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TELEMETRY SYSTEMS CALIBRATION AND VALIDATION HANDBOOK.(U)

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TELEMETRY SYSTEMS CALIBRATION AND VALIDATION HANDBOOK

Federal Electric Corporation
Vandenberg AFB, Calif. 93437

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Vandenberg AFB, Calif. 93437

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TELEMETRY SYSTEMS CALIBRATION AND VALIDATION

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This handbook is prepared to provide informative material for aerospace engineers, range technical operators and planners who are concerned with telemetry systems calibration and validation. Specifically, it is designed to serve as a reference and source document for delineation and standardization of calibration procedures and validation techniques as they apply to the Space and Missile Test Center (SAMTEC) telemetry systems.

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PREFACE

This handbook is the outgrowth of Federal Electric Corporation Performance Analysis Department Report 4000-70-40, Telemetry System Testing, which was published in 1970 to provide up-to-date theory and test procedures for the Space and Missile Test Center (SAMTEC) Vandenberg Air Force Bae, California. The need for this handbook is shown by the fact that over fifty percent of the calibration and validation subjects presented herein were not addressed in the 1970 report. Many changes were brought about by the acquisition of state-of-the-art aerospace ground equipment required to support sophisticated user program requirements at the SAMTEC. A great deal of credit must be given to the Performance Analysis Department for their development of new and improved calibration procedures and validation techniques. Numerous references are made throughout this handbook to the engineering analysis reports and published technical papers of members of the department. Extensive use of new test methods from IRIG (Inter-Range Instrumentation Group), the Pacific Missile Test Center, and Dr. M. H. Nichols/SAMTEC Technical Consultant was made. The contents of this handbook was organized for easy replacement of individual sections because the development of new calibration and validation techniques are continuously in progress.

A review of the table of contents shows many old, familiar titles. But the material in each subsection contains many new and important concepts which have not heretofore been previously gathered into a single reference directed specifically to the task of calibration and validation of aerospace ground support telemetry systems. Direct application of basic calibration techniques is now possible in many areas where complex procedures were previously required to overcome system accuracy limitations only a few years ago. The primary areas of development since 1970 are improvement of the existing antenna solar calibration program, development of the "pop" noise error model for PCM/FM, the implementation of noise power ratio (NPR) tests for frequency division multiplex, improvement of diversity combiner performance through development of calibration and validation methods, implementation of computer controlled test equipment to perform these validation tests rapidly, development of a unique method to obtain a very accurate time tag correlation with data, development of calibration and validation methods for a data source selector which performs a real-time merge with corrected time tagging of four asynchronous PCM streams, improvement of analog tape recording and playback through use of tape signatures and the development of user transmission link models for planning range support.

The improvements to the antenna solar calibration program began in 1970 when directional couplers were first installed to obtain more accurate signal strength calibrations. The measurement results of the directional coupler method showed less variation than the results of the attenuator method. The reduction in variations was discovered to be the better quality attenuators used by the signal generator manufacturers. When high quality variable attenuators became available as individual items, both methods provided equal results. In 1975 the first computer controlled measurement system was installed and offered several advantages which are now proving themselves. Variations have been reduced by use of a digital readout power meter to prevent misinterpretation of meter readings caused by parallax, by use of electronically switched attenuators to avoid gear backlash errors and attenuator dial reading errors and by use of the linear receiver or wattmeter measurement method rather than the attenuator or directional coupler method. The linear receiver method measures on and off sun power directly with a power meter to obtain the high accuracy of the meter (which is normally used to calibrate attenuators). In 1970 a measurement was made at a single radio frequency in about five minutes with a repeatability of ± 3db. Today the measurement is made for 100 frequencies in the same time with a repeatability of better than ± 2db. Measurement accuracy is ± 1db and the causes of the variations in repeatability are being isolated.

Bit Error Rate (BER) tests have often shown that errors occur at signal-to-noise ratio's (SNR) above the normal levels where thermal noise would cause errors for PCM/FM. A model has been developed for planning transmission link formats and has been tested on SAMTEC systems to show that when the receiver IF filter is much wider than the data spectrum "pop" noise occurs. These pops cause bit errors at higher SNR than system thermal noise in many cases. Models are provided with supporting data to show the amount of degradation caused by not using the optimum carrier deviation. Several user transmission links at the SAMTEC must radiate inefficiently due to vehicle constraints, e.g., change of bit rate during flight without changing PCM voltage level for correct deviation. The resulting degradation was formerly attributed to ground support system limitations. Because of this knowledge, better range planning and post flight analysis of ground support systems is now possible.

Noise power ratio (NPR) tests now validate frequency division multiplex transmission links as quickly and easily as BER tests validate PCM transmission links. The system under test is loaded with band limited white noise from a noise generator to simulate full channel loading conditions. For RF transmission tests, the RF carrier is modulated with the noise. A noise receiver (or a calibrated spectrum analyzer) at the system output is adjusted to a reference level. A quiet channel (or notch) is then produced by activating a bandstop filter in the noise generator. A band pass filter corresponding to the quiet channel is selected in the receiver. The difference between the reference level on noise and the quiet channel level is the NPR. NPR can then be used to compute the subcarrier discriminator output SNR for any given subcarrier. Test results are provided to support the theory which shows that transmission link efficiency is strongly dependent on carrier deviation.

The diversity combiner improvement program was successful, in large part, because of a unique multipath simulator developed by Dr. M. H. Nichols. The simulator produces a RF signal fade by phase cancellation created in the same manner as multipath. A signal is split in a power divider then the two signals are added again in another power divider but one of the two signals is shifted in phase by a voltage controlled phase shifter. By changing the control voltage, fades can be induced at any desired rate. This simulator permitted the testing needed to determine the critical combiner control settings for best operation. Steady state conditions did not show the need for these adjustments. The simulator is also used in the acceptance testing of new equipment and for rapid combiner prelaunch readiness checks.

The Telemetry Validation Systems (TVS) demonstrate the effective integration of minicomputers into RF equipment control. These systems automatically perform antenna solar calibrations, PCM BER tests, diversity combiner dynamic fade tests and NPR tests. The flexibility of these systems cannot be described briefly. The requirement for these systems becomes clear when the large number of receivers, combiners and tape recorders needed to support multiple RF links from a test vehicle is counted. The need becomes more pronounced when simultaneous operations are supported on a daily basis.

Special techniques for system calibration and validation are the trademark of the department. Reoccuring problems such as analog tape playback and duplication have been resolved through the use of tape signatures. The tape signature has evolved into a data signature which is also used to verify predetection signal playback equipment operation. But the signature is still constrained to a thirty second tape leader. Another area where special techniques are employed is the time correlation generator which inserts a time tag in received data before recording so that playback and processing errors can be compensated for. Still another area where new techniques were developed is the first of its kind (at the SAMTEC) data source selector which merges asynchronous PCM data streams and provides corrected time tags.

One of the major goals of this period was completed when the "Telemetry Planning Data" report was published. The large number of user data formats supported by the SAMTEC have not been reproduced in this handbook but all of the respective transmission link models are presented with illustrative examples.

The objective of this handbook is to provide a tool to make the transition from in-depth theory to the daily practice of field testing of telemetry ground support equipment. Updates will be made to the individual sections of this handbook as they are developed.

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SECTION 1

ACQUISITION AND TRACKING SYSTEMS

This section of the Telemetry System Calibration and Validation (TSCV) Handbook addresses SAMTEC telemetry acquisition and tracking systems calibration and validation theory and procedures. The section is divided into eleven (11) subsections as follows:

1.1 Solar Calibration

1.2 Receiver Center Frequency and IF Bandwidth

1.3 Signal Generator Calibration

1.4 Deviation Measurement of a Transmitted Signal

1.5 RF Bandwidth Determination

1.6 Bit Error Rate Test

1.7 Diversity Combiner Test

1.8 Notch Noise Power Ratio Test

1.9 Antenna Radiation Pattern Measurement

1.10 Antenna Pointing Capability

1.11 Telemetry Signal Strength Conversion Procedure

1.1 SOLAR CALIBRATION

Solar calibration tests are conducted at all SAMTEC telemetry receive/record sites. The purpose of these solar calibration tests is to determine a figure of merit that represents the capability of a system to support an operation. The figure of merit can be used to predict a signal-to-noise ratio (SNR) at the receiving system output. The SNR is determined by the signal strength at the receiving site, the receiving system antenna power gain (G_r) and the system noise temperature (T_s). The figure of merit is defined as the ratio of G_r to T_s, i.e., $M = G_r/T_s$. For more detailed information regarding figure of merit, refer to the topic 1.1.3 at the end of this procedure.

Theory and procedures for three methods of measuring M are presented. In each case, the sun is used as the calibrated radiation source. The results obtained are more accurate than the laboratory or antenna field measurements for the determination of either gain or system noise temperature independently. In most cases, measurements provide absolute values within 10% accuracy. Solar calibrations are now required for mission support and are requested by the range user to assist in his data evaluation. The solar calibration program was instituted at the SAMTEC in 1970 as a basis for calibration, trouble shooting, operational planning and determining premission "Go/No-go" status. One of the primary advantages of the technique is its applicability to nearly any antenna with an area greater than one square meter operating in the 1400-2300 MHz range. Aperture correction factors are easily computed for antennas with greater than 50 dB gain where the sun cannot be treated as a point source due to narrow antenna beamwidth.

Basic references for the solar calibration technique are:

> "The Sun as a Calibration Signal Source for L and S Band Telemetry," Proceedings of the International Telemetering Conference, Vol IV, (October 1968), 330.
>
> "Impact of Solar Calibration on Telemetry System Testing and Checkout," Proceedings of the International Telemetering Conference, Vol VIII, (October 1972).
>
> Report 4000-70-09, Solar Flux Measurements. Vandenberg AFB, California: FEC Performance Analysis Directorate, March 1970.
> Report 30-70-58, Discussion of Solar Testing Techniques. Vandenberg AFB, California: FEC Performance Analysis Directorate, September 1970.

1.1.1 Theory

The signal-to-noise ratio (SNR) at the receiver IF output of a telemetry sytem is dependent on the signal power at the antenna, the antenna power

gain (G_r) and the noise temperature of the system (T_s). A figure of merit, M, exists where

$$M = \frac{G_r}{T_s} \tag{1}$$

A more useful figure of merit is M' where

$$M' \equiv 10 \log_{10} M = \text{Antenna gain (dB)} - 10 \log_{10} T_s \tag{2}$$

The SNR at the IF output is

$$SNR = \frac{J_a M \lambda^2}{4\pi KB} = \frac{J_a G_r \lambda^2}{4\pi K T_s B} \tag{3}$$

where

B = the effective system noise bandwidth which is normally considered to be the receiver IF bandwidth,

K = Boltzmann's constant = 1.380622×10^{-23} watts/Hz-°K,

λ = the wavelength of the received signal in meters.

J_a = received power density in watts/meter^2.

The figure of merit has to be determined before SNR can be calculated. Consider the system shown in Figure 1. The system noise temperature referenced to the antenna feed is given by

$$T_s = T_{sky} + T_{background} + T_\eta + \frac{T_o(\overline{NF} - 1)}{\eta} \tag{4}$$

where

$$T_\eta = \frac{(1 - \eta)\, T_o}{\eta}$$

T_o = 290°K (by definition).

T_{sky} = noise temperature at the antenna feed from galactic contributions with the antenna not pointed at the sun (at least three beamwidths away from the sun).

$T_{background}$ = noise temperature at the antenna feed from earth noise, atmospheric losses etc. but excluding galactic contributions. 53°K is a reasonable approximation for 1400 to 2300 MHz systems under 30 meters in diameter.

$\overline{NF}$ = noise figure of the receiving system following and including the preamplifier.

η = transmission efficiency of the transmission line from the feed to the preamp. For example, a 1.5 dB line loss would be η = .708 or T_s = 119°K while 1.0 dB loss would be only η = .794 and T_s = 75°K because loss in dB = 10 log $\frac{1}{\eta}$. So η = 1/antilog (loss in dB/10).

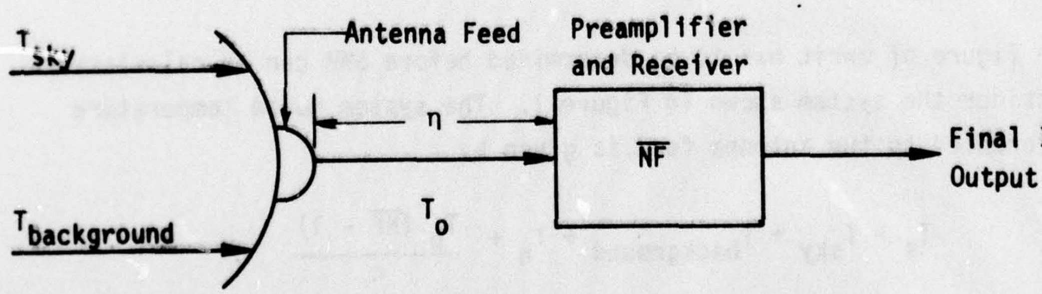


FIGURE 1. SIMPLIFIED RECEIVING SYSTEM

The solar calibration technique is used to measure the ratio of the noise temperatures, T_{sun}/T_s, where T_{sun} is the noise temperature at the antenna feed due to the noise from the sun.

By definition,

$$T_{sun} = \frac{F\ G_r\ \ \lambda^2}{8\pi KL} \tag{5}$$

where

F = total solar flux density of random polarization at the receiving antenna at the measurement frequency in watts/ m^2-Hz

G_r = power gain of the receiving antenna

λ = measurement frequency wavelength in meters

L = aperture correction factor for high gain or conical scan antennas

Note: A polarization factor of 1/2 for single polarization is included.

Daily solar flux measurements are readily available via the Astrogeophysical Teletype Network (ATN) from the Sagamore Hill Radio Observatory and the Manila Radio Observatory at 1415 and 2695 MHz and from the Algonquin Radio Observatory (Ottawa) at 2800 MHz. These measurements may be interpolated satisfactorily using the nearest available frequency of measurements to the 1435 to 1535 MHz and 2200 to 2300 MHz bands with the use of the following relation:

$$F = F_o\left(\frac{f}{f_o}\right)^{\sigma} \tag{6}$$

where

F_o = measured flux density in watts/meter^2-Hz

f = frequency of the system being tested

f_o = frequency of the flux density measurement

σ = spectral index, the value of which depends on F_o and can be obtained from Table I.

Table I Recommended Values of σ for Various Ranges of Flux Density [1]

f_o = 1415 MHz	f_o = 2695 MHz or 2800 MHz	Values of σ
$40\text{-}84 \times 10^{-22}$	$60\text{-}124 \times 10^{-22}$	0.6
$85\text{-}109 \times 10^{-22}$	$125\text{-}149 \times 10^{-22}$	0.5
$110\text{-}135 \times 10^{-22}$	$150\text{-}180 \times 10^{-22}$	0.4

The noise temperature ratio (T_{sun}/T_s) is related to the figure of merit (M) in the following way,

$$\frac{T_{sun}}{T_s} = \frac{F\lambda^2}{8\pi KL}\frac{G_r}{T_s} = \frac{F\lambda^2 M}{8\pi KL} \tag{7}$$

Therefore,

$$M = \frac{8\pi KL}{F\lambda^2}\left(\frac{T_{sun}}{F_s}\right) \tag{8}$$

or

$$M' = 10\log_{10}(8\pi K) + 10\log_{10}L + 10\log_{10}\left(\frac{T_{sun}}{T_s}\right) - 10\log_{10}F - 20\log_{10}\lambda \tag{9}$$

[1] Guidice, D. A. and J. P. Castelli, "The Use of Extraterrestrial Radio Sources in the Measurement of Antenna Parameters," IEEE Transactions on Aerospace and Electronic Systems, Vol AES-7, No. 2 (March 1971).

In order to calculate M', two more physical quantities, L and λ, have to be determined first. The wavelength λ can be easily determined by the operating frequency by using the following equation

$$\lambda = \frac{c}{f}$$

where f is the RF carrier frequency under test and $c = 3 \times 10^8$ msec, the speed of light.

The aperture correction factor depends on the angular size of the sun (ϕ_s) and the 3 dB beamwidth of the antenna (ϕ_a). If simultaneous lobing is used

$$L \approx \left[1 + 0.18 \left(\frac{\phi_s}{\phi_a}\right)^2\right]^2 , \qquad \phi_s/\phi_a \leq 1 \tag{10}$$

For con-scan systems

$$L \approx \left[1 + 0.18 \left(\frac{\phi_s}{\phi_a}\right)^2\right]^2 \left[\frac{\dfrac{P_{sun\ (con\text{-}scan\ off)}}{P_{cold}} - 1}{\dfrac{P_{sun\ (con\text{-}scan\ on)}}{P_{cold}} - 1}\right] \tag{11}$$

Note: In this equation, ϕ_a is the 3 dB beamwidth with con-scan off.

P_{sun} = IF output power, antenna on the sun

P_{cold} = IF output power, antenna on the cold sky

There are three popular methods of determining the ratio T_{sun}/T_s: the variable attenuator method, the directional coupler method (also called the signal generator method), and the linear receiver method.

Variable Attenuator Method - In this method the overall system gain is adjusted so that the IF output power remains unchanged when the antenna is pointed first to the cold sky and then to the sun. Because the IF output power is held constant, a linear gain receiver is not required. The system gain is varied by adjusting an attenuator which is inserted between the preamplifier and the receiver. The system configuration diagram for this method is shown in Figure 2.

The general procedure can be described in the following way. Observe the power output (P_1) of the IF amplfier with the antenna pointed at the cold sky when the transmission coefficient of the attenuator is set at η_o. With the antenna pointed at the sun, adjust the attenuator to a transmission coefficient (η_s) for which the IF power output (P_2) is equal to P_1. The equation used to calculate the noise temperature ratio in this method is given as

$$\frac{T_{sun}}{T_s} = \frac{\eta_o}{\eta_s} - 1 \tag{1}$$

The basic assumptions for this method are:

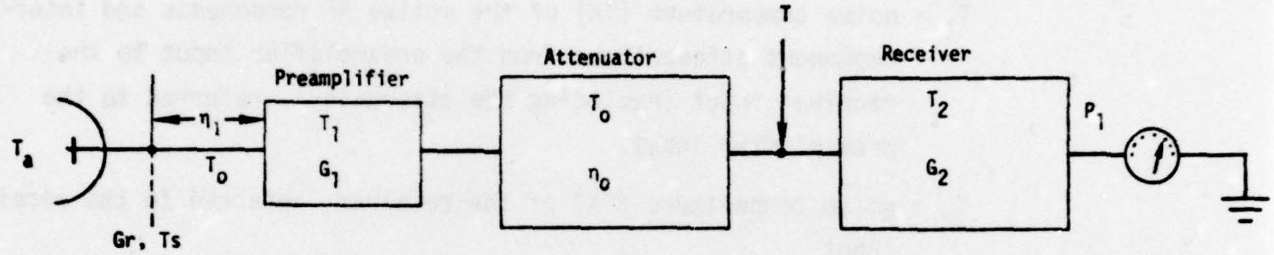
(1) Preamplifier linear over range of input power P_1 to $4P_2$.

(2) $T_s \eta_1 G_1 \eta_o >> (T_o + T_2)$, that is, the noise temperature of the receiver is negligible compared with the noise temperature at the receiver input due to the noise sources in the rest of the system. Preamplifier gain normally assures this condition is met.

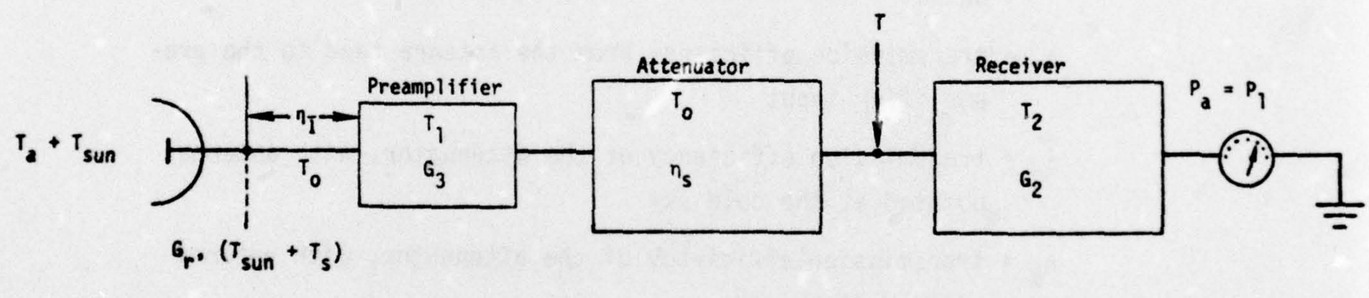
(3) An accurately calibrated and matched attenuator is used.

Equation (1) can be easily derived by using temperatures only. First, the antenna is pointed at the cold sky and the attenuator is set with a transmission efficiency of η_o, as shown in Figure 2 (a). Under this condition, the noise temperature, which is referred to the input of the receiver, is given as,

$$T = [T_a \eta_1 + (1 - \eta_1) T_o + T_1] G_1 \eta_o + (1 - \eta_o) T_o \tag{2}$$



(a) Antenna Pointed At the Cold Sky



(b) Antenna Pointed At The Sun

FIGURE 2 SYSTEM CONFIGURATION FOR THE VARIABLE ATTENUATOR METHOD

where

T_a = antenna noise temperature (°K) when the antenna is pointed at the cold sky

T_o = physical temperature (°K) of the variable attenuator and the transmission line between the antenna feed and the preamplifier input, i.e., 290°K

T_1 = noise temperature (°K) of the active RF components and inter-component attenuations from the preamplifier input to the receiver input (excluding the attenuator), referred to the preamplifier input

T_2 = noise temperature (°K) of the receiver, referred to the receiver input

G_1, G_3 = transmission efficiencies from the preamplifier input to the attenuator input, with antenna pointed at the cold sky and the sun, respectively

G_2 = transmission efficiency from the receiver input to the IF output

η_1 = transmission efficiency from the antenna feed to the pre-amplifier input

η_o = transmission efficiency of the attenuator, with antenna pointed at the cold sky

η_s = transmission efficiency of the attenuator, with antenna pointed at the sun

When the attenuation is increased as shown in Figure 2 (b), the noise temperature T can be expressed as (under the assumption of linear response of the preamplifier $G_3 = G_1$)

$$T = [(T_a + T_{sun}) \eta_1 + (1 - \eta_1) T_o + T_1] G_1 \eta_s + (1 - \eta_s) T_o \qquad (3)$$

Since the attenuator is set for constant receiver IF power output, the right-hand members of Equations (2) and (3) must be equal. Thus,

$$T_a + \frac{(1 - \eta_1)}{\eta_1} T_o + \frac{T_1}{\eta_1} = \frac{T_{sun}\, G_1\, \eta_s + (\eta_o - \eta_s)\, \frac{T_o}{\eta_1}}{G_1\, (\eta_o - \eta_s)} \tag{4}$$

The system noise temperature is

$$T_s = T_a + \frac{(1 - \eta_1)}{\eta_1} T_o + \frac{T_1}{\eta_1} + \frac{(1 - \eta_o)\, T_o}{\eta_o G_1 \eta_1} + \frac{T_2}{\eta_o G_1 \eta_1} \tag{5}$$

Substitution of Equation (4) for the first three terms on the right-hand side of Equation (5) yields

$$T_s = T_{sun} \frac{1}{\frac{\eta_o}{\eta_s} - 1} + \frac{T_o + T_2}{\eta_o G_1 \eta_1} \tag{6}$$

If

$$T_s \gg \frac{(T_o + T_2)}{\eta_1 G_1 \eta_o}, \tag{7}$$

Then

$$T_s \simeq T_{sun} \frac{1}{\frac{\eta_o}{\eta_s} - 1} \tag{8}$$

Therefore,

$$\frac{T_{sun}}{T_s} = \frac{\eta_o}{\eta_s} - 1 \tag{9}$$

In order to show that $T_s \eta_1 G_1 \eta_o \gg (T_o + T_2)$, the following test should be made:

(1) Point antenna at cold sky and set the attenuator to give η_o. Record output power P_1.

(2) Increase attenuator setting relative to step (1) by at least 30 dB. Record output power P_2.

Then, if P_1/P_2 exceeds 20 (13 dB), the excess noise temperature of the receiver adds less than 0.2 dB to the measured figure of merit.

Directional Coupler Method - In this method, a directional coupler and a S-band signal generator with variable output are needed.

The general procedure can be better described by referring to Figure 3. With antenna pointed at the cold sky, the manual gain of the receiver set so that the system gain is in the linear region, and the output of the signal generator adjusted to the minimum (P_{so}), the IF output power is recorded as P_1. Then the output of the signal generator is increased until the IF output power is doubled. The output of the signal generator is recorded as P_{s1}. Now point the antenna at the sun and reduce the output of the signal generator to the minimum. The manual gain of the receiver is adjusted so the IF output power is P_1. Next point the antenna at the cold sky and increase the output of the signal generator until the IF output reaches P_1. The output of the signal generator is recorded as P_{s2}. The equation used to calculate the noise temperature ratio in this method is

$$\frac{T_{sun}}{T_s} = \frac{P_{s2}}{P_{s1}} \qquad (1)$$

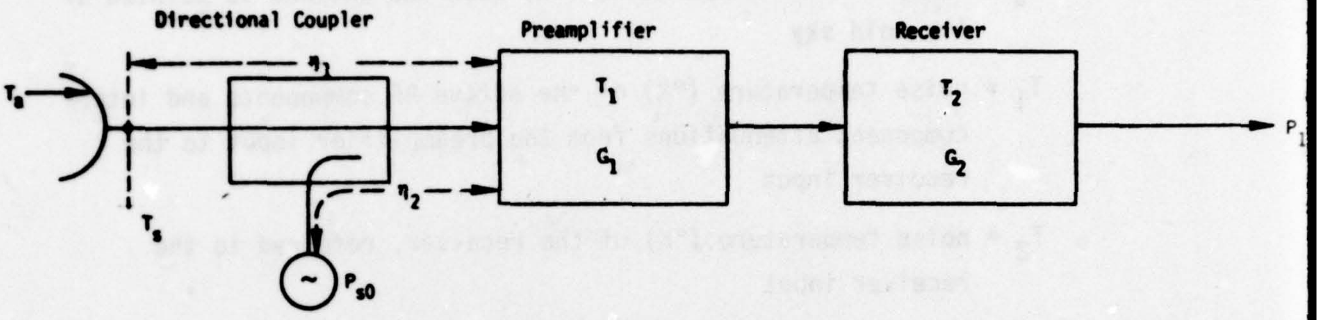
The primary criteria for using the directional coupler method are:

(1) The directional coupler must be matched at the preamplifier input for test signal injection

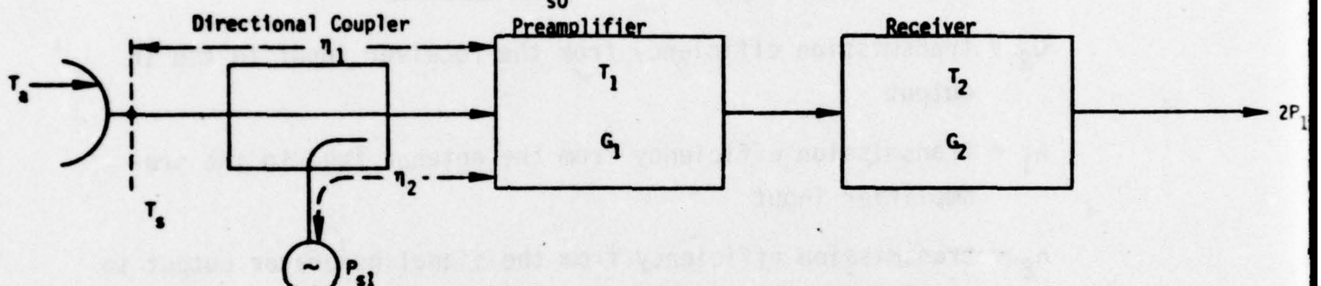
(2) The variable output RF signal generator should be accurately calibrated. The attenuator scale of the generator should allow the operator to reset the attenuator to within several tenths dB when returning to a reference setting after making adjustments.

(3) The receiving system output is linear (i.e., G_1 G_2 is constant) over the range from P_1 to $2P_1$.

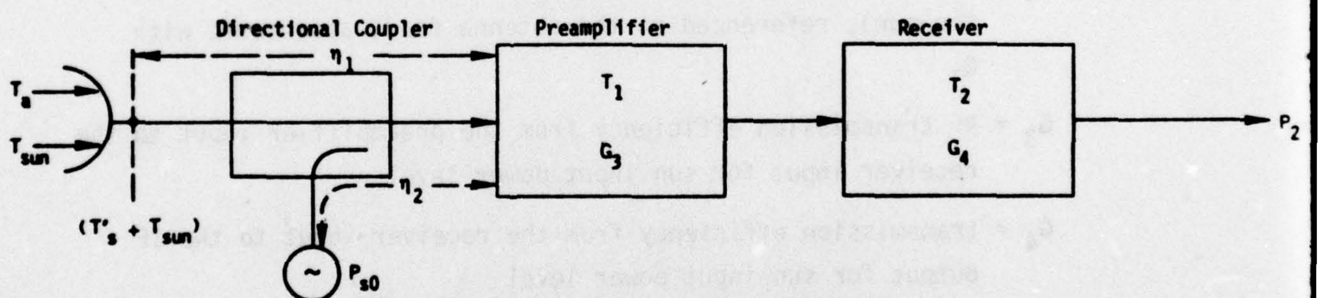
(4) The power outputs of the signal generator P_{s1} and P_{s2} are much larger than the minimum output P_{so}.



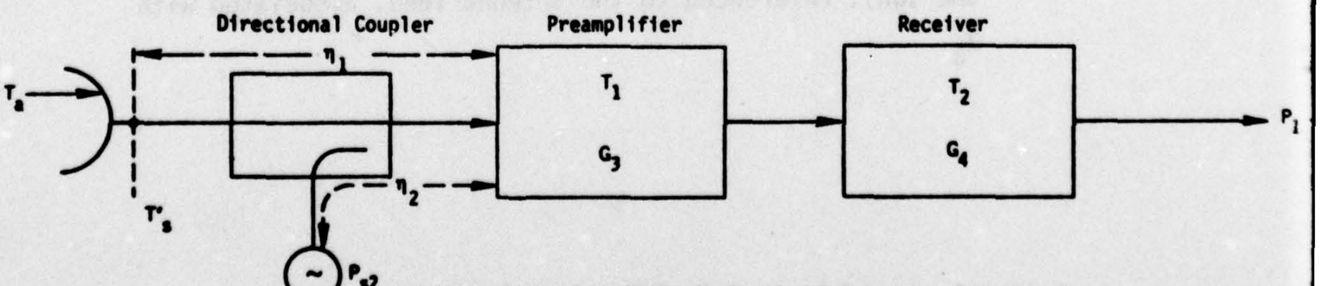
(a) Antenna Pointed at "Cold Sky"; Signal Generator Output at Minimum = P_{s0}



(b) Antenna Pointed at "Cold Sky"; Signal Generator Output = P_{s1} Such That IF Output = $2P_1$



(c) Antenna Pointed at Sun; Signal Generator Output = P_{s0}, Receiver IF Gain Decreased Such That IF Output = P_1



(d) Antenna Pointed at "Cold Sky"; Signal Generator Output = P_{s2} Such That IF Output = P_1

FIGURE 3 SYSTEM CONFIGURATION FOR THE DIRECTIONAL COUPLER METHOD

The parameters depicted in Figure 3 and used in the derivation of Equation (1) are:

T_a = antenna noise temperature (°K) when the antenna is pointed at the cold sky

T_1 = noise temperature (°K) of the active RF components and inter-component attenuations from the preamplifier input to the receiver input

T_2 = noise temperature (°K) of the receiver, referred to the receiver input

G_1 = RF transmission efficiency from the preamplifier input to the receiver input

G_2 = transmission efficiency from the receiver input to the IF output

η_1 = transmission efficiency from the antenna feed to the pre-amplifier input

η_2 = transmission efficiency from the signal generator output to the preamplifier input

T_s = system noise temperature (excluding the contribution from the sun), referenced to the antenna feed, associated with G_1

G_3 = RF transmission efficiency from the preamplifier input to the receiver input for sun input power level

G_4 = transmission efficiency from the receiver input to the IF output for sun input power level

T_s' = system noise temperature (excluding the contribution from the sun), referenced to the antenna feed, associated with G_3

Equation (1) can be proved by establishing the mathematical relationships among the IF power output, the noise temperatures and the output of the signal generator for each procedure step. When the antenna is first pointed to the cold sky, the IF power output is

$$P_1 = P_{so}\, \eta_2\, G_1\, G_2 + T_s\, \eta_1\, G_1\, G_2\, KB \tag{2}$$

on cold sky, refer to Figure 3 (a)

The first term accounts for the IF power output originated from the signal generator and the second term represents the IF power output due to the system noise. While keeping the antenna pointed to the cold sky, the output of the signal generator is increased until the IF output is doubled ($2P_1$). Since the range from P_1 to $2P_1$ is within the previously verified linear range of the receiving system, i.e., $G_1\, G_2$ is constant over the power range from P_1 to $2P_1$, it follows that

$$2P_1 = P_{s1}\, \eta_2\, G_1\, G_2 + T_s\, \eta_1\, G_1\, G_2\, KB \tag{3}$$

on cold sky, refer to Figure 3 (b)

Then substituting equation (2) into equation (3) yields

$$T_s\, \eta_1\, KB = (P_{s1} - 2P_{so})\, \eta_2 \tag{4}$$

Next, with the antenna pointed on the sun, the signal generator output is adjusted back to P_{so} and the IF gain is decreased for the IF output of P_1,

$$P_1 = P_{so}\, \eta_2\, G_3\, G_4 + (T_s' + Tsun)\, \eta_1\, G_3\, G_4\, KB \tag{5}$$

on sun, refer to Figure 3 (c)

Finally, with the antenna pointed at the cold sky and the signal generator output increased to P_{s2} such that the IF output is again P_1, it follows that

$$P_1 = P_{s2}\, \eta_2\, G_3\, G_4 + T_s'\, \eta_1\, G_3\, G_4\, KB \tag{6}$$

on cold sky, refer to Figure 3 (d)

After equating the right-hand sides of equations (5) and (6) and performing reductions, the following equation is obtained:

$$T_{sun}\ \eta_1\ KB = (P_{s2} - P_{so})\ \eta_2 \tag{7}$$

Equation (7) can be divided by equation (4) to yield

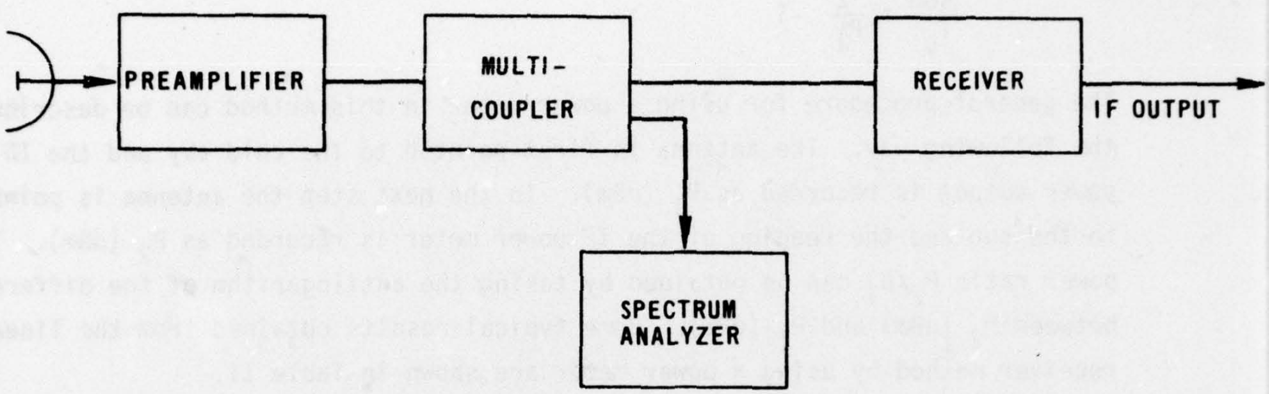
$$\frac{T_{sun}}{T_s} = \frac{(P_{s2} - P_{so})}{(P_{s1} - 2P_{so})} \tag{8}$$

If $P_{so} << P_{s1}, P_{s2}$, then equation (8) is reduced to the expression commonly used with the directional coupler method,

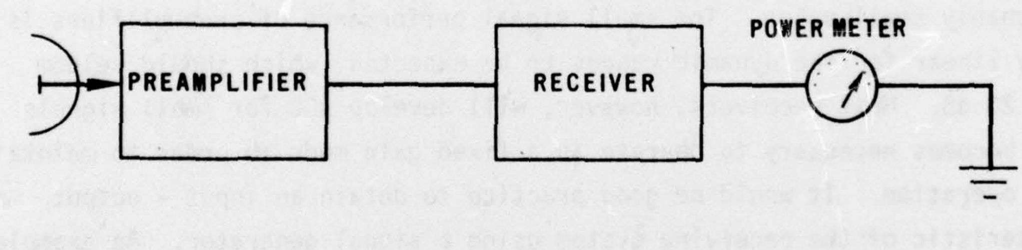
$$\frac{T_{sun}}{T_s} \simeq \frac{P_{s2}}{P_{s1}} \tag{9}$$

Linear Receiver Method - In this method, the power levels of the receiving systems are measured when the antenna is pointed at the cold sky and then at the sun. The system configuration for this method is shown in Figure 4. Either a power meter or a spectrum analyzer can be used to measure the output power levels. One of the advantages in using a spectrum analyzer is that the system figure of merit across the entire bandwidth can be viewed.

The general procedure for using a spectrum analyzer in this method is described here. The spectrum analyzer input is connected to the output of the multicoupler, as shown in Figure 4 (a). The scan width and center frequency of the analyzer should be selected so the receiving system bandwidth or a desired portion thereof will appear on the display. The analyzer bandwidth should be small enough to provide a high resolution. With the antenna pointed to the cold sky and no attenuation set in the analyzer attenuator, store the cold sky power spectrum. Then disconnect the analyzer from the multicoupler so that only noise power generated internally in the analyzer will be displayed. Store the analyzer noise spectrum. This noise spectrum should be at least 10 dB below the cold sky power spectrum for this method to be effective. After clearing the display, direct the antenna toward the sun and store the sun power spectrum. Then point the antenna to cold sky and store the cold sky power spectrum. The display may be photographed for



(a) USING SPECTRUM ANALYZER



(b) USING POWER METER

FIGURE 4   SYSTEM CONFIGURATION FOR LINEAR RECEIVER METHOD

permanent record. A typical display is shown in Figure 5. The power ratio P_2/P_1 can be obtained by taking antilogarithm of the difference of P_2 reading (on sun) at center frequency minus P_1 reading (on cold sky) at the same frequency. The ratio of the noise temperatures, T_{sun}/T_s, is related to the power ratio in the following form,

$$\frac{T_{sun}}{T_s} = \frac{P_2}{P_1} - 1 \tag{1}$$

The general procedure for using a power meter in this method can be described in the following way. The antenna is first pointed to the cold sky and the IF power output is recorded as P_1 (dBm). In the next step the antenna is pointed to the sun and the reading of the IF power meter is recorded as P_2 (dBm). The power ratio P_2/P_1 can be obtained by taking the antilogarithm of the difference between P_2 (dBm) and P_1 (dBm). Some typical results obtained from the linear receiver method by using a power meter are shown in Table II.

Equation (1) can be applied again to relate the power ratio with the noise temperature ratio.

The receiving system must be linear over an input power range from P_1 to $4P_2$ in order to reduce error due to peak power exceeding average power to a reasonably small value. The small signal performance of preamplifiers is usually linear for the dynamic ranges to be expected, which should seldom exceed 20 dB. Most receivers, however, will develop AGC for small signals and it becomes necessary to operate in a fixed gain mode in order to maintain linear operation. It would be good practice to obtain an input - output characteristic of the receiving system using a signal generator. An example of such a characteristic is shown in Figure 6 for a particular receiver.

The mathematical derivation of equation (1) is provided here. With the antenna pointed at the cold sky, the reading of the power meter is

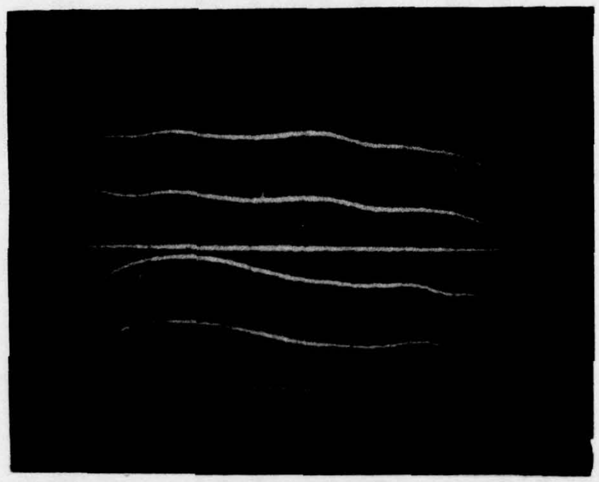
$$P_1 = T_s \, KBA_1 \tag{2}$$

where B = effective noise bandwidth of the IF

A_1 = power gain of the system

Top 3 traces for RH
on sun
off sun
analyzer noise

Bottom 3 traces for LH
on sun
off sun
analyzer noise



Analyzer Settings: Vertical Scale = 10 dB/cm
Horizontal Scale = 20 Mhz/cm
IF BW = 100 kHz

Figure 5 Typical Spectrum Analyzer Display for the Linear Receiver Method (performed on GKR-7 antenna at TRS, 22 March 1974)

TABLE II

SOLAR CALIBRATION 35 FT. ANTENNA   DAY 321,1976   2307 HRS GMT
SOLAR FLUX = 73   SUN CONDITION GRE   APERTURE CORRECTION = 0.60

FREQ	POLARITY	P_1 COLD	P_2 SUN	DIFF	M'	ODB
2202.5	LH	-22.19	-7.20	14.99	20.1	-111.4
	RH	-18.67	-2.43	16.24	21.3	-112.7
2204.5	LH	-21.60	-6.69	14.91	20.0	-111.4
	RH	-18.13	-2.51	15.62	20.7	-112.1
2206.5	LH	-21.67	-7.01	14.66	19.7	-111.1
	RH	-17.84	-2.46	15.38	20.5	-111.8
2208.5	LH	-21.95	-7.59	14.36	19.4	-110.8
	RH	-17.77	-2.53	15.24	20.3	-111.7
2210.5	LH	-21.58	-7.09	14.49	19.6	-110.9
	RH	-18.09	-2.95	15.14	20.2	-111.6
2212.5	LH	-21.17	-6.31	14.86	20.0	-111.3
	RH	-18.32	-3.05	15.27	20.4	-111.8
2214.5	LH	-20.82	-5.56	15.26	20.4	-111.7
	RH	-18.50	-3.12	15.38	20.5	-111.9
2216.5	LH	-20.68	-5.23	15.45	20.6	-112.0
	RH	-18.47	-2.90	15.57	20.7	-112.1
2218.5	LH	-20.69	-5.17	15.52	20.6	-112.0
	RH	-18.21	-2.66	15.55	20.7	-112.1
2220.5	LH	-20.49	-4.62	15.67	20.8	-112.2
	RH	-18.55	-2.93	15.62	20.8	-112.1
2222.5	LH	-20.54	-4.84	15.70	20.8	-112.2
	RH	-18.89	-3.28	15.61	20.8	-112.1
2224.5	LH	-20.35	-4.64	15.71	20.9	-112.2
	RH	-19.06	-3.48	15.58	20.7	-112.1
2226.5	LH	-20.80	-5.21	15.59	20.7	-112.1
	RH	-18.99	-3.46	15.53	20.7	-112.1
2228.5	LH	-20.27	-4.61	15.66	20.8	-112.2
	RH	-18.54	-3.07	15.47	20.6	-112.0
2230.5	LH	-20.05	-4.48	15.57	20.7	-112.1
	RH	-18.36	-2.90	15.46	20.6	-112.0
2232.5	LH	-19.94	-4.35	15.59	20.8	-112.1
	RH	-18.20	-2.83	15.37	20.5	-111.9
2234.5	LH	-19.30	-3.68	15.62	20.8	-112.2
	RH	-18.02	-2.77	15.25	20.4	-111.8
2236.5	LH	-19.28	-3.78	15.50	20.7	-112.1
	RH	-18.02	-2.82	15.20	20.4	-111.8
2238.5	LH	-19.59	-4.17	15.42	20.6	-112.0
	RH	-18.36	-3.18	15.18	20.4	-111.7
2240.5	LH	-19.27	-3.95	15.32	20.5	-111.9
	RH	-18.27	-3.32	14.95	20.1	-111.5
2242.5	LH	-19.60	-4.34	15.26	20.5	-111.8
	RH	-17.89	-3.11	14.78	20.0	-111.3
2244.5	LH	-19.94	-4.76	15.18	20.4	-111.8
	RH	-18.02	-3.03	14.99	20.2	-111.6
2246.5	LH	-19.67	-4.15	15.52	20.7	-112.1
	RH	-18.61	-3.34	15.27	20.5	-111.9
2248.5	LH	-19.46	-3.70	15.76	21.0	-112.4
	RH	-18.99	-3.50	15.49	20.7	-112.1
2250.5	LH	-19.22	-3.37	15.85	21.1	-112.5
	RH	-19.13	-3.52	15.61	20.8	-112.2

TABLE II (CONTINUED)

SOLAR CALIBRATION 35 FT. ANTENNA DAY 321,1976 2307 HRS GMT
SOLAR FLUX = 73 SUN CONDITION GRE APERTURE CORRECTION = 0.60

FREQ	POLARITY	P_1 COLD	P_2 SUN	DIFF	M'	ODB
2252.5	LH	-19.38	-3.51	15.87	21.1	-112.5
	RH	-18.86	-3.18	15.68	20.9	-112.3
2254.5	LH	-19.59	-3.81	15.78	21.0	-112.4
	RH	-18.84	-3.16	15.68	20.9	-112.3
2256.5	LH	-19.70	-3.98	15.72	21.0	-112.3
	RH	-18.97	-3.32	15.65	20.9	-112.3
2258.5	LH	-19.63	-3.81	15.82	21.1	-112.5
	RH	-19.07	-3.40	15.67	20.9	-112.3
2260.5	LH	-19.50	-3.72	15.78	21.0	-112.4
	RH	-18.90	-3.29	15.61	20.9	-112.2
2262.5	LH	-18.89	-3.19	15.70	21.0	-112.3
	RH	-18.09	-2.56	15.53	20.8	-112.2
2264.5	LH	-18.34	-2.69	15.65	20.9	-112.3
	RH	-17.54	-2.19	15.35	20.6	-112.0
2266.5	LH	-18.01	-2.42	15.59	20.9	-112.2
	RH	-17.54	-2.21	15.33	20.6	-112.0
2268.5	LH	-17.66	-2.19	15.47	20.7	-112.1
	RH	-17.82	-2.46	15.36	20.6	-112.0
2270.5	LH	-17.43	-2.09	15.34	20.6	-112.0
	RH	-17.36	-2.18	15.18	20.4	-111.8
2272.5	LH	-17.46	-2.21	15.25	20.5	-111.9
	RH	-17.30	-2.27	15.03	20.3	-111.7
2274.5	LH	-17.48	-2.33	15.15	20.4	-111.8
	RH	-16.94	-2.14	14.80	20.1	-111.4
2276.5	LH	-17.42	-2.32	15.10	20.4	-111.8
	RH	-17.00	-2.24	14.76	20.0	-111.4
2278.5	LH	-17.60	-2.37	15.23	20.5	-111.9
	RH	-17.05	-2.15	14.90	20.2	-111.6
2280.5	LH	-17.87	-2.37	15.50	20.8	-112.2
	RH	-17.33	-2.15	15.18	20.5	-111.9
2282.5	LH	-18.07	-2.44	15.63	20.9	-112.3
	RH	-17.88	-2.49	15.39	20.7	-112.1
2284.5	LH	-18.17	-2.54	15.63	21.0	-112.3
	RH	-18.97	-3.55	15.42	20.7	-112.1
2286.5	LH	-18.32	-2.67	15.65	21.0	-112.4
	RH	-19.09	-3.69	15.40	20.7	-112.1
2288.5	LH	-18.69	-3.01	15.68	21.0	-112.4
	RH	-19.05	-3.63	15.42	20.7	-112.1
2290.5	LH	-19.21	-3.58	15.63	21.0	-112.3
	RH	-18.47	-3.13	15.34	20.7	-112.1
2292.5	LH	-18.52	-3.06	15.46	20.8	-112.2
	RH	-18.37	-3.17	15.20	20.5	-111.9
2294.5	LH	-18.35	-2.96	15.39	20.7	-112.1
	RH	-18.82	-3.75	15.07	20.4	-111.8
2296.5	LH	-18.30	-3.04	15.26	20.6	-112.0
	RH	-19.06	-4.08	14.98	20.3	-111.7
2298.5	LH	-18.07	-2.89	15.18	20.5	-111.9
	RH	-19.04	-4.08	14.96	20.3	-111.7
2299.5	LH	-18.07	-2.88	15.19	20.5	-111.9
	RH	-18.68	-3.67	15.01	20.4	-111.7

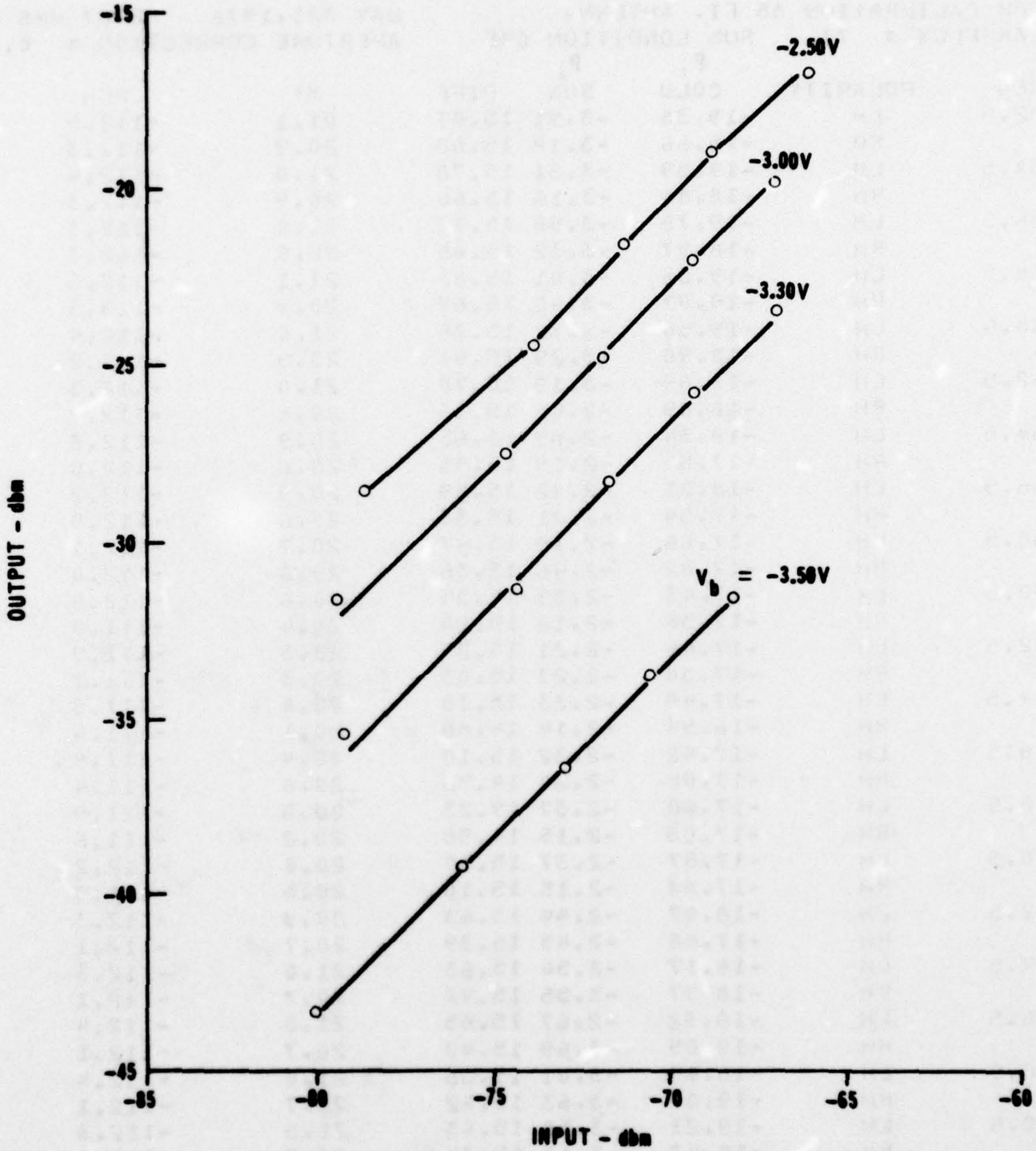


FIGURE 6 **RECEIVER LINEARITY**

When the antenna is pointed at the sun, the reading of the meter is recorded as P_2,

$$P_2 = T_2 \; KBA_2 \tag{3}$$

where $T_2 = T_{sun} + T_s$

A_2 = power gain of the system at the sun input power level.

Equation (3) can be divided by equation (2) to obtain the ratio of the above power readings,

$$\frac{P_2}{P_1} = \frac{T_2 \; A_2}{T_s \; A_1} \tag{4}$$

If the receiver system is linear within the power range from P_1 to $2P_2$, i.e., $A_1 = A_2$, then

$$\frac{P_2}{P_1} = \frac{T_2}{T_s} = \frac{T_{sun}}{T_s} + 1 \tag{5}$$

Equation (5) can be rearranged into the following form,

$$\frac{T_{sun}}{T_s} = \frac{P_2}{P_1} - 1 \tag{6}$$

1.1.2 Test Procedures

Attenuator Method - The proper receiving system test configuration is shown in Figure 7. Note the power meter must be connected to the linear IF output.

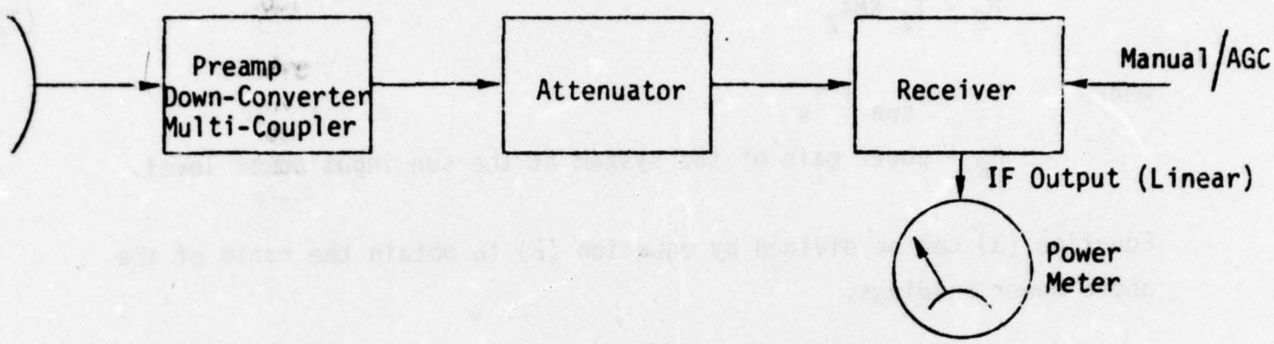


Figure 7 Configuration for Attenuator Method

The procedure consists of the following steps:

Antenna on cold sky (same elevation as the sun and several beamwidths behind in azimuth.)

1. Attenuator at 0 dB attenuation
2. Receiver AGC in auto mode
3. Record IF output power P_1 (dBm)
4. Receiver AGC to manual mode
5. Adjust manual gain until power meter reads P_1

Antenna on sun (autotrack or manual slew for maximum meter reading).

6. Adjust attenuator until IF power is P_1 gain
7. Record attenuator dial setting L_a (dB)

Antenna on cold sky

8. Attenuator to maximum attenuator
9. Record IF output power P_2 (dBm).

10. P_1 (dBm) - P_2 (dBm) must be greater than 13 dB or method is invalid.

11. Obtain solar flux density from site source

12. Record frequency of measurement

13. Refer to computer tabulation for determining M' values with values obtained in Steps 11, 12 and 7. (See sample on pg. 30)

14. Locate M' value from tabulation and record

15. Add the aperture correction factor L (dB) to M' and record as corrected M'.

The following procedure need only be done once at the beginning of a solar testing program to validate the system.

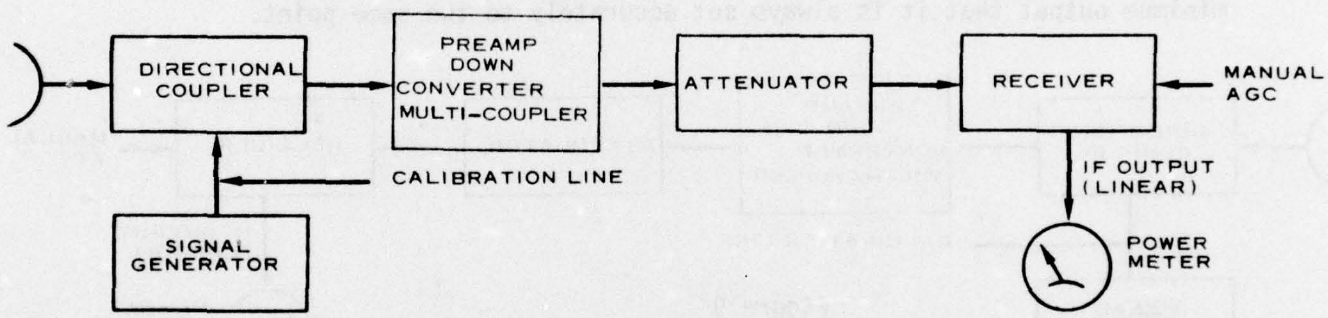


Figure 8. Configuration for Validation Procedure

1. Insert a directional coupler between the antenna feed and the preamp input as shown in Figure 8.

2. Connect a signal generator to the directional coupler through a calibration line and set to the frequency of the system being tested.

<u>Antenna on cold sky</u>

3. Attenuator at 0 dB attenuation

4. Signal generator at minimum output

5. Record IF power P_1 (dBm)

6. Increase the signal generator output until the IF power increases 3 dB over P_1

7. Record the signal generator setting P_{1gen} (dBm)
8. Set the attenuator to the same value as that obtained in step 7 of the Attenuator Method Procedure.
9. Increase the signal generator output until the power meter reads P_1 again.
10. Record the signal generator setting as P_{2gen} (dBm).
11. Subtract P_{1gen} (dBm) (step 7) from P_{2gen} (dBm) (step 10)

    If this difference is $\pm$ 0.2 dB of the value of L_a (dB) in step 7 of the Attenuator Method Procedure, the attenuator method is valid.

Directional Coupler Method - The proper receiving system test configuration is shown in Figure 9. It is important when the generator is set to a minimum output that it is always set accurately to the same point.

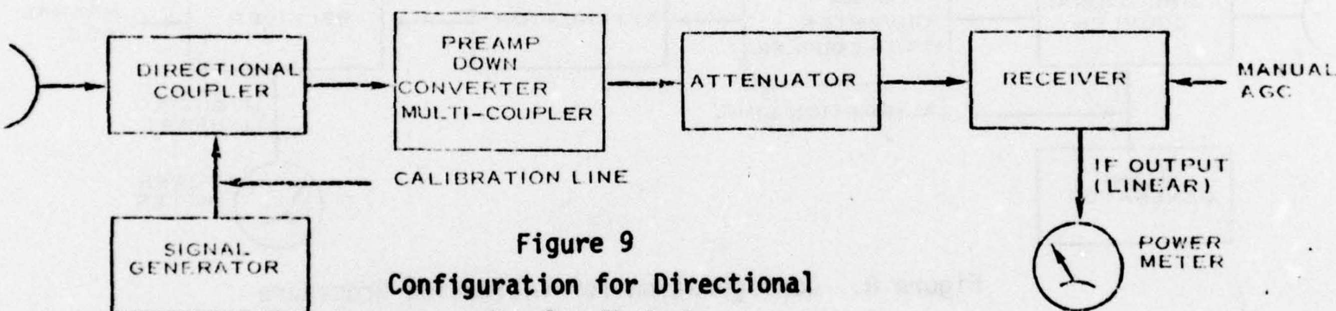


Figure 9
Configuration for Directional Coupler Method

The procedure consists of the following steps:

Antenna on cold sky (same elevation as the sun and several beamwidths behind in azimuth.)

1. Signal generator at minimum output
2. Receiver AGC in auto mode
3. Record IF output power P_1 (dBm)
4. Set AGC to manual mode
5. Adjust manual AGC until power meter reads P_1 (dBm)

6. Increase signal generator output until the IF output power increases 3 dB over P_1 (dBm)

7. Record signal generator setting P_{1gen} (dBm)

<u>Antenna on sun</u>

8. Signal generator at minimum output

9. Adjust manual AGC until IF output power is approximately P_1 (dBm)

<u>Antenna on cold sky</u>

10. Increase signal generator output until IF power returns to P_1

11. Record signal generator setting P_{2gen} (dBm)

12. Subtract P_{1gen} (dBm) from P_{2gen} (dBm)

13. Record frequency of test

14. Obtain solar flux density from site source

15. Refer to computer tabulation for determining M' values with values obtained in steps 12, 13, and 14. (See sample on pg. 30)

    Locate M' value from tabulation and record

    Add aperture correction factor L (dB) to M' and record as corrected M'.

<u>Spectrum Analyzer Method</u> - The proper receiving system test configuration is shown in Figure 10.

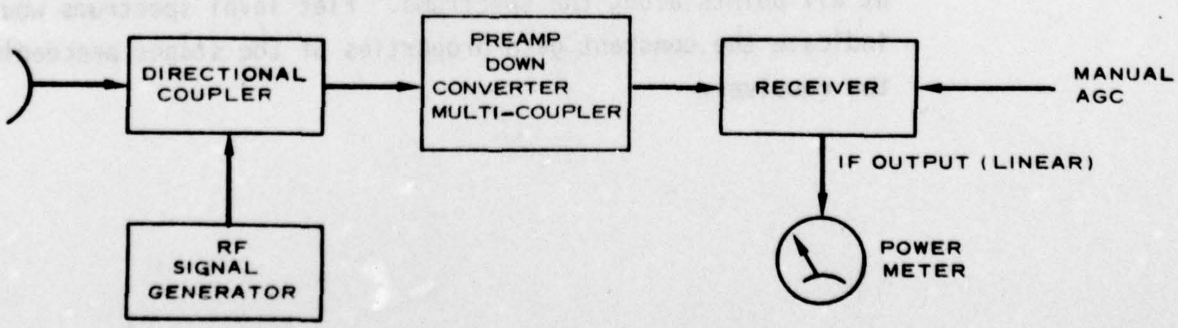


Figure 10. Configuration for Spectrum Analyzer Method

The procedure consists of the following steps:

Antenna on cold sky

1. Set scan width and center frequency of the spectrum analyzer so the bandwidth of the receiving system appears in full on the display
2. Make sure spectrum analyzer attenuator is at 0 dB attenuation
3. Unplug spectrum analyzer from multicoupler
4. Initiate a single sweep
5. Reconnect spectrum analyser input to multicoupler
6. Initiate a single sweep
7. Press STORE control (If the two stored spectrums do not interfere with each other, the procedure is valid.)
8. ERASE display

Antenna on sun

9. Initiate a single sweep
10. Antenna on cold sky
11. Initiate a single sweep
12. Press STORE control
13. Photograph display
14. Analyze photo. For constant M' values across the bandwidth, the vertical distance between the spectrums should be constant at all points along the spectrums. Flat level spectrums would indicate the constant gain properties of the stages preceeding the receiver.

Input Format - The data format of the single input card is summarized in Table III.

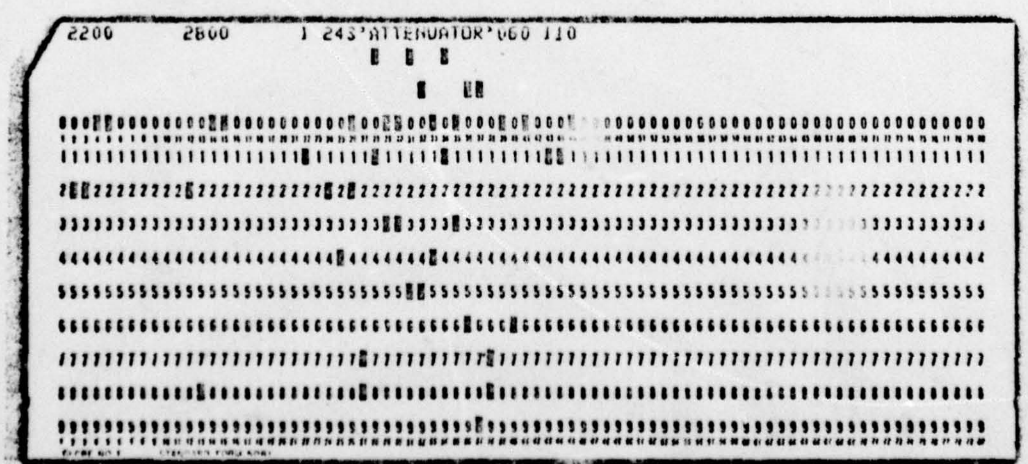
TABLE III Input Format for MPRIME

Card Number	Column Number	Description	Program ID	Format
1	2-11	Start Frequency in Mhz	F	F10.0
	12-21	Frequency of Flux Reading in Mhz	FB	F10.0
	22-23	Start at this dB reading	IDBF	I2
	24-25	Stop at this dB reading	IDBL	I2
	26	Frequency Band, L = 1435 - 1535 Mhz S = 2200 - 2300 Mhz	LS	A1
	27-38	Measurement Method - "Attenuator" or "Sig Gen'	ID	3A4
	39	Method Flag, 0 = Attenuator, 1 = Signal Generator	IMOD	I1
	40-42	Start at this flux reading	IFLUX	I3
	43-45	Stop at this flux reading	LFLUX	I3

Example - In order to illustrate the use of the figure of merit program, let us consider preparing a tabulation of figure of merit values which can be used in the 2200 Mhz to 2300 Mhz frequency band for any antenna up to 30 meters in diameter.

TABLE IV Input Data for MPRIME Example

Card No. 1



The program output is a 96 page printout - one page for each of the solar flux readings. Page one of the program output is shown in Table V. For an on/off the sun attenuator change of 2.0 dB (left hand column) for a typical 8 foot parabola at 2285 MHz, M' - L' = 3.5. On the other hand, a 35 foot parabola would have an on/off sun change of 14.5 dB at 2285 MHz. M' - L' = 20.1 from the table for the 14.5 dB attenuator change at a solar flux of 60.

Program Listing - Table VI contains a listing of the main program while Table VII contains a listing of the subroutine used by the main program.

TABLE V MPRIME TABULATION

S-BAND FIGURE OF MERIT
ATTENUATOR METHOD

SOLAR FLUX = 60. MEASURED AT 2800. MEGAHERTZ

SET.	2200	2205	2210	2215	2220	2225	2230	2235	2240	2245	2250	2255	2260	2265	2270	2275	2280	2285	2290	2295	2300
1.0	-0.3	-0.3	-0.3	-0.3	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.0
1.5	1.7	1.7	1.7	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.9	1.9	2.0	2.0	2.0
2.0	3.2	3.2	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.5	3.5	3.5	3.5
2.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.7	4.7	4.7	4.7	4.7	4.7	4.7
3.0	5.5	5.5	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.8	5.8	5.8	5.8	5.8
3.5	6.5	6.5	6.5	6.5	6.5	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.8
4.0	7.3	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.6	7.6	7.6	7.6	7.6	7.6
4.5	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.4	8.4	8.4	8.4	8.4	8.4
5.0	8.9	8.9	8.9	8.9	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.2	9.2
5.5	9.6	9.6	9.6	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.9	9.9	9.9
6.0	10.3	10.3	10.3	10.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.6
6.5	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.2	11.2	11.2	11.2	11.2	11.2
7.0	11.6	11.6	11.6	11.6	11.6	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.9
7.5	12.2	12.2	12.2	12.2	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.5	12.5
8.0	12.8	12.8	12.8	12.8	12.8	12.9	12.9	12.9	12.9	12.9	12.9	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.1	13.1
8.5	13.4	13.4	13.4	13.4	13.4	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.7
9.0	14.0	14.0	14.0	14.0	14.0	14.0	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.2	14.2	14.2	14.2	14.2	14.2	14.2
9.5	14.5	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.8	14.8	14.8	14.8	14.8
10.0	15.1	15.1	15.1	15.1	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.4	15.4
10.5	15.6	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.9	15.9	15.9	15.9	15.9	15.9
11.0	16.2	16.2	16.2	16.2	16.2	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.5	16.5
11.5	16.7	16.7	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.9	16.9	16.9	16.9	16.9	16.9	16.9	17.0	17.0	17.0	17.0	17.0
12.0	17.3	17.3	17.3	17.3	17.3	17.3	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.5	17.5	17.5	17.5	17.5	17.5	17.5
12.5	17.8	17.8	17.8	17.8	17.9	17.9	17.9	17.9	17.9	17.9	17.9	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.1	18.1
13.0	18.3	18.3	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.6	18.6	18.6	18.6
13.5	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.1	19.1	19.1	19.1	19.1	19.1
14.0	19.4	19.4	19.4	19.4	19.4	19.4	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6
14.5	19.9	19.9	19.9	19.9	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.2	20.2
15.0	20.4	20.4	20.4	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.7	20.7	20.7
15.5	20.9	20.9	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.2	21.2	21.2	21.2
16.0	21.4	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.7	21.7	21.7	21.7	21.7
16.5	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.1	22.2	22.2	22.2	22.2	22.2	22.2
17.0	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.6	22.6	22.6	22.6	22.6	22.6	22.6	22.7	22.7	22.7	22.7	22.7	22.7	22.7
17.5	23.0	23.0	23.0	23.0	23.0	23.0	23.1	23.1	23.1	23.1	23.1	23.1	23.1	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2
18.0	23.5	23.5	23.5	23.5	23.5	23.6	23.6	23.6	23.6	23.6	23.6	23.6	23.6	23.7	23.7	23.7	23.7	23.7	23.7	23.7	23.8
18.5	24.0	24.0	24.0	24.0	24.0	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.2	24.2	24.2	24.2	24.2	24.2	24.2	24.2	24.3
19.0	24.5	24.5	24.5	24.5	24.6	24.6	24.6	24.6	24.6	24.6	24.6	24.6	24.7	24.7	24.7	24.7	24.7	24.7	24.7	24.7	24.8
19.5	25.0	25.0	25.0	25.0	25.1	25.1	25.1	25.1	25.1	25.1	25.1	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.3	25.3
20.0	25.5	25.5	25.5	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.8	25.8	25.8
20.5	26.0	26.0	26.0	26.1	26.1	26.1	26.1	26.1	26.1	26.1	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.3	26.3	26.3
21.0	26.5	26.5	26.5	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.8	26.8	26.8
21.5	27.0	27.0	27.1	27.1	27.1	27.1	27.1	27.1	27.1	27.1	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.3	27.3	27.3	27.3
22.0	27.5	27.5	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.8	27.8	27.8	27.8
22.5	28.0	28.0	28.1	28.1	28.1	28.1	28.1	28.1	28.1	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.3	28.3	28.3	28.3
23.0	28.5	28.5	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.8	28.8	28.8	28.8
23.5	29.0	29.0	29.1	29.1	29.1	29.1	29.1	29.1	29.1	29.2	29.2	29.2	29.2	29.2	29.2	29.2	29.3	29.3	29.3	29.3	29.3
24.0	29.5	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.7	29.7	29.7	29.7	29.7	29.7	29.7	29.8	29.8	29.8	29.8	29.8
24.5	30.0	30.1	30.1	30.1	30.1	30.1	30.1	30.1	30.1	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.3	30.3	30.3	30.3	30.3
25.0	30.5	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.7	30.7	30.7	30.7	30.7	30.7	30.7	30.8	30.8	30.8	30.8	30.8
25.5	31.0	31.1	31.1	31.1	31.1	31.1	31.1	31.1	31.2	31.2	31.2	31.2	31.2	31.2	31.2	31.2	31.3	31.3	31.3	31.3	31.3
26.0	31.5	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.8	31.8	31.8	31.8	31.8
26.5	32.0	32.1	32.1	32.1	32.1	32.1	32.1	32.1	32.2	32.2	32.2	32.2	32.2	32.2	32.2	32.2	32.3	32.3	32.3	32.3	32.3
27.0	32.5	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.8	32.8	32.8	32.8	32.8

TABLE VI

MAIN PROGRAM

```
FORTRAN IV G LEVEL  21                    MAIN                 DATE = 75356          10/20/53

                     IMPLICIT REAL *8 (A-H,O-Z)
                     COMMON /PRIME/ EXP,F,FB,FLUX,T2,IDBF,IDBL
                     DIMENSION DMP(22),ID(3)
                     READ(5,1)F,FB,IDBF,IDBL,LS,(ID(IJ),IJ=1,3),IMOD,IFLUX,LFLUX
                   1 FORMAT(1X,2F10.0,2I2,A1,3A4,I1,2I3)
                     BK=0.138D0
                     PI=3.14159362500
                     T2=10D0*DLOG10(8D0*PI*BK)
                     FLUX=DFLOAT(IFLUX)
                     IDBL=(IDBL*2)-1
                     IPAGE=1
                     IF(FB.EQ.2800D0) GO TO 20
                     DO 10 I=IFLUX,LFLUX
                     IF(FLUX.GE.40D0.AND.FLUX.LT.85D0) EXP=0.6D0
                     IF(FLUX.GE.85D0.AND.FLUX.LT.110D0) EXP=0.5D0
                     IF(FLUX.GE.110D0.AND.FLUX.LE.135D0) EXP=0.4D0
                     WRITE(6,200) LS,IPAGE,(ID(IJ),IJ=1,3),FLUX,FB
                     WRITE(6,201)
                     CALL MPRIME
                     FLUX=FLUX+1D0
                     IPAGE=IPAGE+1
                  10 CONTINUE
                     GO TO 30
                  20 DO 19 I=IFLUX,LFLUX
                     IF(FLUX.GE.60D0.AND.FLUX.LT.125D0) EXP=0.6D0
                     IF(FLUX.GE.125D0.AND.FLUX.LT.150D0) EXP=0.5D0
                     IF(FLUX.GE.150D0.AND.FLUX.LE.180D0) EXP=0.4D0
                     WRITE(6,200) LS,IPAGE,(ID(IJ),IJ=1,3),FLUX,FB
                     WRITE(6,101)
                     CALL MPRIME
                     FLUX=FLUX+1D0
                     IPAGE=IPAGE+1
                  19 CONTINUE
                 101 FORMAT    (' SET.   2200   2205   2210   2215   2220   2225   2230   2235
                    *2240   2245   2250   2255   2260   2265   2270   2275   2280   2285   2290
                    *2295   2300')
                 200 FORMAT(1H1,46X,A1,'-BAND',5X,'FIGURE OF MERIT',48X,'PAGE',I3/,51X,
                    *3A4,'METHOD',//,40X,'SOLAR FLUX = ',F4.0,'  MEASURED AT ',
                    *F5.0,'    MEGAHERTZ'/)
                 201 FORMAT    (' SET.   1435   1440   1445   1450   1455   1460   1465   1470
                    *1475   1480   1485   1490   1495   1500   1505   1510   1515   1520   1525
                    *1530   1535')
                  30 CONTINUE
                     END

FORTRAN IV G LEVEL  21                    MAIN                 DATE = 75356          10/20/53

      *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
      *OPTIONS IN EFFECT*  NAME = MAIN     , LINECNT =        60
      *STATISTICS*    SOURCE STATEMENTS =        38,PROGRAM SIZE =      2148
      *STATISTICS*  NO DIAGNOSTICS GENERATED
```

TABLE VII SUBROUTINE MPRIME

```
FORTRAN IV G LEVEL  21                MPRIME              DATE = 75356          10/20/53

      SUBROUTINE MPRIME
      IMPLICIT REAL *8 (A-H,O-Z)
      COMMON /PRIME/ EXP,F,FB,FLUX,T2,IDBF,IDBL
      DIMENSION DMP(22)
      ADB=DFLOAT(IDBF)
      DO 9 K=IDBF,IDBL
      DF=F
      DO 8 IK=1,21
      X=ADB/10D0
      T1=10D0*DLOG10((10D0**X)-1D0)
      IF(IMOD.EQ.1) T1=10D0*DLOG10(10D0**X)
      T=(DF/FB)**EXP
      TT=(300D0/DF)**2
      T3=10D0*DLOG10(FLUX*TT*T)
      DMP(IK)=T1+T2-T3
      DF=DF+5D0
    8 CONTINUE
      WRITE(6,1)ADB,(DMP(J),J=1,21)
    1 FORMAT(1X,F4.1,21(2X,F4.1))
      ADB=ADB+0.5D0
    9 CONTINUE
      RETURN
      END

FORTRAN IV G LEVEL  21                MPRIME              DATE = 75356          10/20/53

*OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
*OPTIONS IN EFFECT*  NAME = MPRIME   , LINECNT =        60
*STATISTICS*     SOURCE STATEMENTS =        23,PROGRAM SIZE =      1072
*STATISTICS*  NO DIAGNOSTICS GENERATED

*STATISTICS*  NO DIAGNOSTICS THIS STEP
```

1.2 RECEIVER CENTER FREQUENCY AND IF BANDWIDTH

1.2.1 Theory

There are two performed tests with a spectrum analyzer that validate receiver operational readiness in only a few minutes. These are the center frequency test and receiver IF and quieting test. An experienced operator is able to verify correct alignment of the receiver circuitry, by monitoring the receiver IF output with the spectrum analyzer, the IF filter shape and bandpass are easily verified. Correct alignment of receiver tuning circuitry is verified at the same time by nulling the tuning meter and observing the position of the carrier in the bandpass. Receiver demodulator alignment is then verified by performing a 20 dB quieting check and observing the video output of an oscilloscope. These tests are also valid for certification of tape recorder alignment. Spectrum photographs and oscilloscope photographs are provided to illustrate various types of misalignment.

1.2.2 Test Procedures

These procedures are taken from:

> Report 4000-70-40, Telemetry System Testing. Vandenberg AFB, California: FEC Performance Analysis Directorate, June 1970.

Center Frequency Test - The purpose of this test is to verify that the telemetry receivers are tuned to the center frequency of the incoming signal. A spectrum analyzer and and RF signal generator are connected in the normal operating configuration as shown in Figure 1.

1. Set the signal generator for the operational frequency, using either crystal mode of VFO. If the VFO mode is used, verify the center frequency with a counter.
2. Connect the signal generator to the receivers via the system test cable.

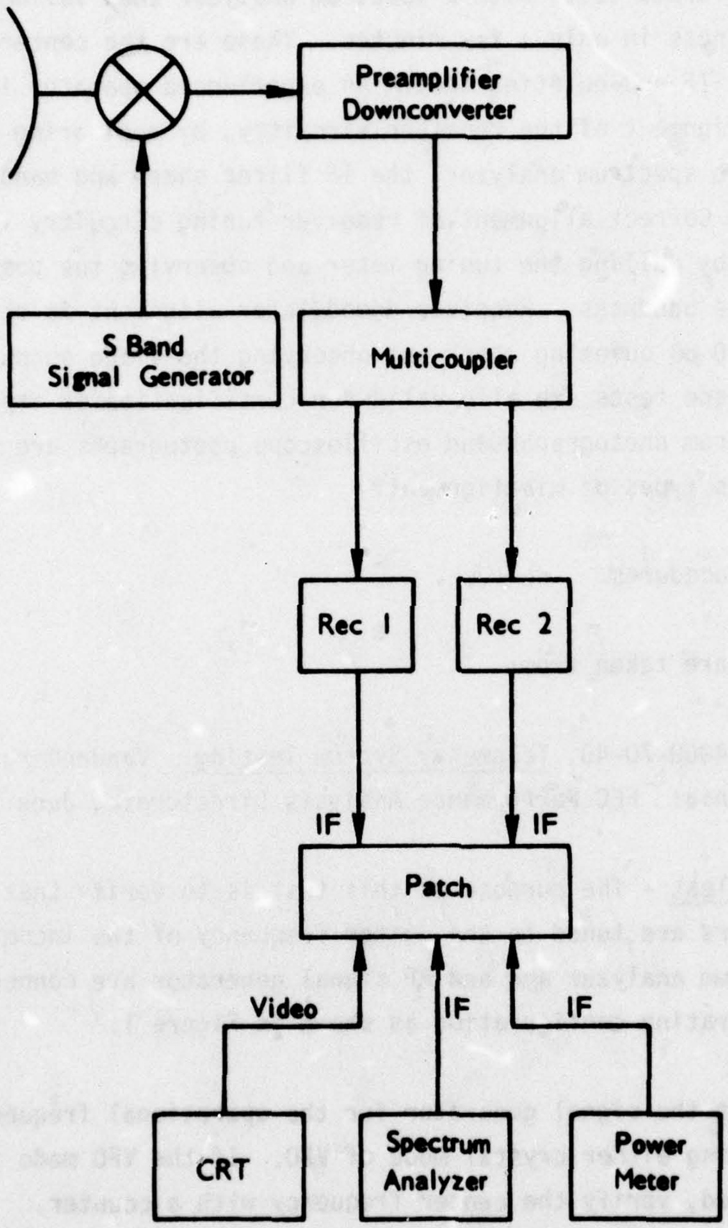


FIGURE 1 RECEIVER AND IF QUIETING TEST

3. Tune all receivers to the signal generator using the receiver tuning meter.

4. Using the spectrum analyzer, display the 10 MHz IF signal from each receiver and verify the CW signal appears in the center of the IF pass band. The signal generator output is set for approximately 20 dB carrier-to-noise level on the display as shown in Figure 2.

5. In the system operational mode and after the vehicle telemetry begins transmitting, retune receivers as required. Verify correct tuning by displaying the 10 MHz IF signal on the spectrum analyzer and checking for signal at the center of the pass band.

Receiver IF and Quieting - Use the following equipment set up as shown in Figure 1 to check the telemetry receiver IF and quieting characteristics:

RF Signal Generator
Power Meter, HP 431 or equivalent
Spectrum Analyzer
Oscilloscope

1. Set the signal generator to CW and transmit the appropriate RF frequency. Tune the receiver to this frequency.
2. Connect the power meter to the 10 MHz linear IF Output of the receiver to be tested.
3. Reduce the signal generator output level to the minimum setting and measure the receiver IF power.
4. Switch the receiver to manual gain control (MGC) and adjust the gain to give the same IF power as measured in step 3 above.
5. Raise the signal generator output until a 3 dB increase in IF power is observed on the power meter.

6. Record the signal generator dial setting. This setting represents the power required to obtain zero dB S/N in the receiver IF provided step 7 conditions are met. Step 7 is normally performed only to verify this technique is applicable with a particular receiver and is not performed in routine tests.

7. To determine that the receiver is linear with the manual gain setting of step 4 at least over the range 0-3 dB, check to see that the following table is verified:

Ps	IF Output Power	dB increase (relative to N)
Minimum Setting	N	—
P_{si}	2N	3 dB
$2P_{si}$	3N	4.77 dB
$3P_{si}$	4N	6 dB

where P_s = signal generator output power

P_{si} = system noise power with no signal = N

Notes: (1) This linearity check is simply to observe that the power meter reading increases 1.8 dB for a 3 dB increase on the signal generator dial after step 5 (i.e., the initial 3 dB increase in IF power is followed by a 1.8 dB increase). Another 1.2 dB increase on the power meter should be observed when the signal generator output level is increased by 1.8 dB. Accuracies of $\pm$ 0.3 dB are acceptable because the meter and generator dial readings contribute the major errors.

(2) If the table is not verified to within a few tenths of a dB, change the manual gain until a satisfactory operating point for the test is found.

8. Return the receiver to the AGC mode and disconnect the power meter.

9. Connect the spectrum analyzer to the receiver linear 10 MHz IF output. Set the analyzer IF bandwidth to one tenth or less of the receiver IF bandwidth (e.g., an analyzer IF bandwidth of 10 kHz could be used for any receiver IF bandwidth of 100 kHz or more). The remaining analyzer control settings depend on the receiver filter bandwidth. These controls should be set to obtain a display similar to Figure 3.

10. Reduce the signal generator output to minimum and check the receiver noise spectrum for proper width and symmetry (see Figure 3).

11. Connect an oscilloscope to the video output of the receiver. Check the receiver video output for "pop noise" as shown in Figure 4.

12. Increase the signal generator output 7 dB above the 0 dB S/N reference level.

13. Verify that the receiver video output "pop noise" has been quieted (see Figure 5).

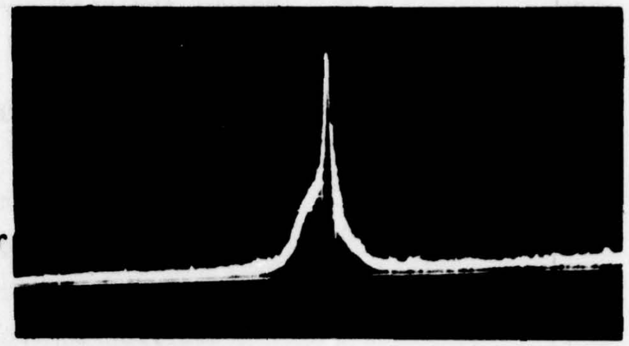


Figure 2

Spectrum Analyzer Display at a 10 MHz IF Signal on a Properly Tuned Receiver

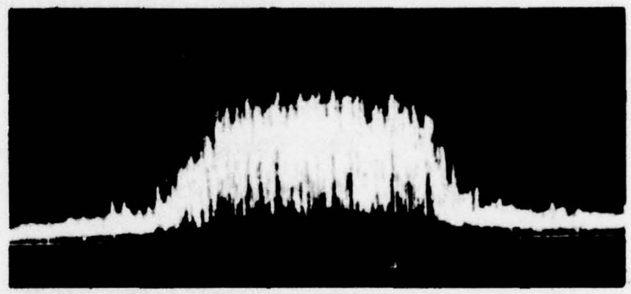


Figure 3

Proper Width and Symmetry of Receiver Noise Spectrum

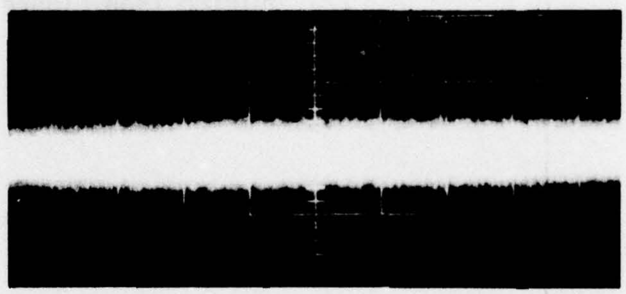


Figure 4

Spectrum Analyzer Display of Receiver Video Output Showing "Pop Noise"

0 dB S/N

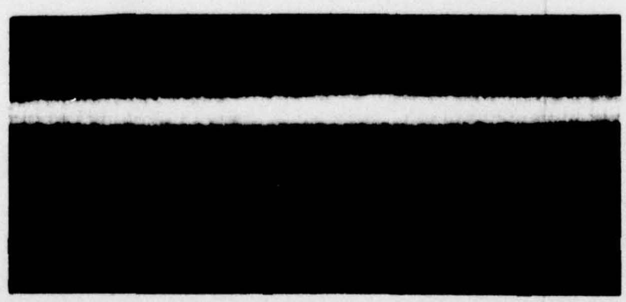


Figure 5

Spectrum Analyzer Display of Receiver Video Output Showing "Pop Noise" Quieted

10 dB S/N

1.3 SIGNAL GENERATOR CALIBRATION

1.3.1 Theory

RF signal generator angle modulation deviation sensitivity S, can be measured in terms of Hz or radians per volt. Then, peak-to-peak deviation is equal to S times the peak-to-peak input voltage. The deviation is equal to S times the rms input voltage. The signal generator sensitivity S, can be adjusted on the front panel. When the peak-to-peak voltage of the input signal is fixed, for example with a certain PCM logic, the sensitivity S can be adjusted to produce the desired peak-to-peak deviaton with this fixed peak-to-peak input voltage without directly measuring S. However, when the input is noiselike, as for example a notch noise test signal or a baseband involving a subcarrier, it is necessary to measure S in terms of rms voltage. In any case, once S is set on the signal generator panel, the control must not be disturbed, otherwise the calibration must be repeated.

Carrier disappearance for sine wave modulation corresponds to a modulation index[1] of 2.4 for FM or a peak phase deviation of 2.4 radians for PM. The ratio of the carrier to the first order sidebands at other modulation indexes for sine wave or square wave input may be determined by inspection of Figure 1. The derivation of the equation from which the curves in Figure 1 were computed is contained in the next paragraph of this section. Since the first carrier null for sine wave modulation occurs at a deviation ratio of 2.4, a convenient frequency to be used for adjusting the RF signal generator deviation is:

$$\text{modulating frequency to be used} = \frac{\text{desired peak frequency deviation}}{2.4}$$

---

[1] Modulation index (β) is defined as $\frac{\Delta f}{f_m}$ or $\frac{\text{peak frequency deviation}}{\text{modulating frequency}}$.

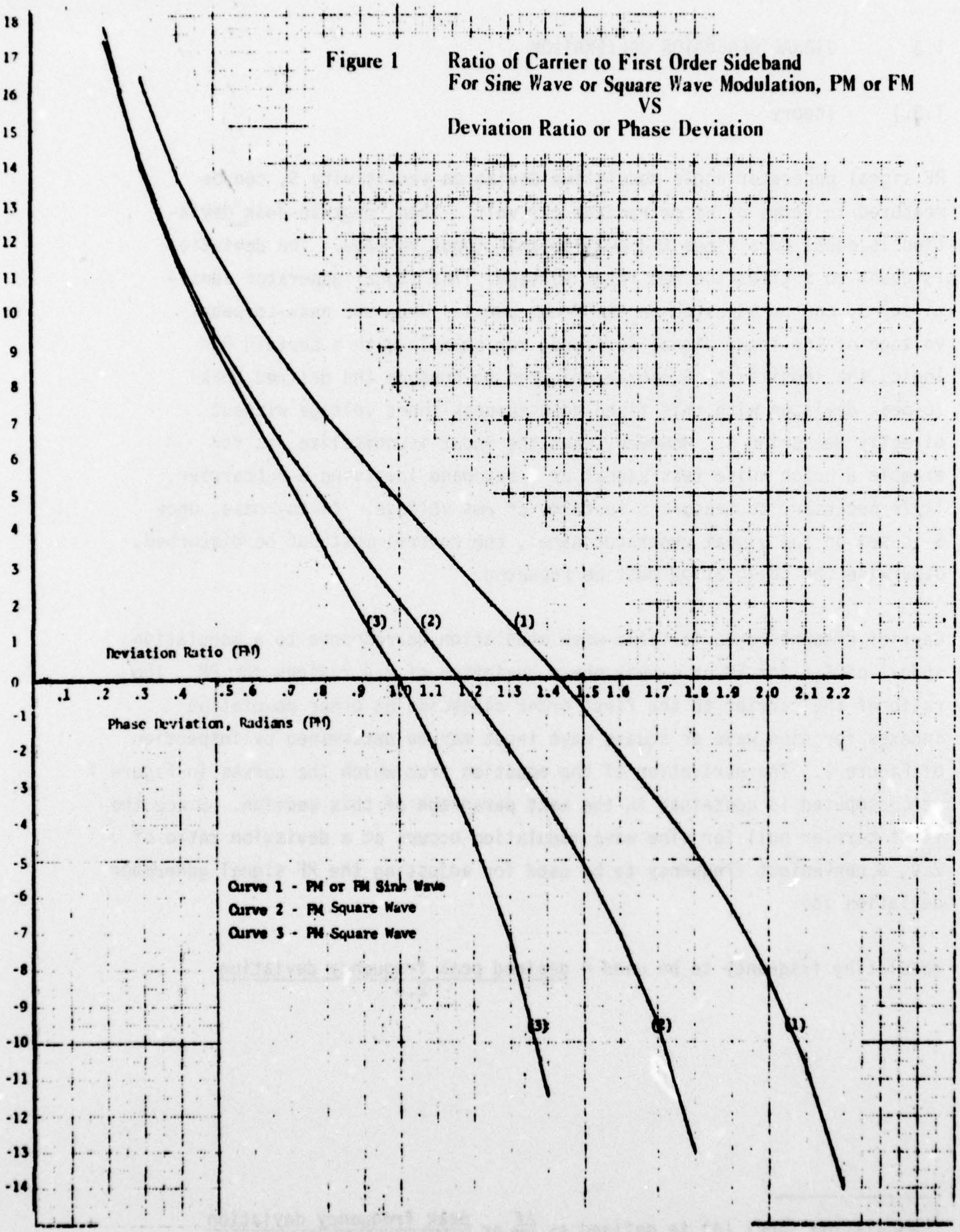


Figure 1
Ratio of Carrier to First Order Sideband
For Sine Wave or Square Wave Modulation, PM or FM
VS
Deviation Ratio or Phase Deviation
Deviation Ratio (FM)
Phase Deviation, Radians (PM)
Curve 1 - PM or FM Sine Wave
Curve 2 - FM Square Wave
Curve 3 - PM Square Wave
(1)
(2)
(3)
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2

Derivation of Carrier to Sideband Ratios - The FM and PM ratios for sine wave modulation are derived directly from the ratio of $J_0(\beta)$ and $J_1(\beta)$, where β equals $\frac{\Delta f\ max}{f_m}$, the ratio of the maximum carrier frequency deviation to the modulating signal frequency for FM, or phase deviation for PM.

The ratio of the carrier to the first order sideband for a carrier frequency modulated by a square wave is given by:

$$\left|\left(\frac{\beta^2-1}{\beta^2}\right)\operatorname{Tan}\frac{\pi}{2}\beta\right|, \text{ where } \beta = \frac{\Delta f max}{f_m} \tag{1}$$

The carrier amplitude, C_0, of a carrier phase modulated by a square wave is given by:

$$C_0 = f_m \int_{-\frac{1}{2f_m}}^{\frac{1}{2f_m}} e^{j\Psi(t)}dt \tag{2}$$

The first order sideband amplitude, C_1, is given by:

$$C_1 = f_m \int_{-\frac{1}{2f_m}}^{\frac{1}{2f_m}} e^{j\Psi(t)} \cdot e^{-j2\pi f_m t} dt \tag{3}$$

$$\text{where } \beta(t) = -\beta \text{ for } -\frac{1}{2f_m} < t < -\frac{1}{4f_m}$$

$$= \beta \text{ for } -\frac{1}{4f_m} < t < \frac{1}{4f_m}$$

$$= -\beta \text{ for } \frac{1}{4f_m} < t < \frac{1}{2f_m}$$

Direct integration yields:

$$\left|\frac{C_0}{C_1}\right| = \left|\frac{\pi}{2} \operatorname{Cot}\beta\right|$$

1.3.2 Test Procedure

FM Generator Deviation Calibration

Carrier Null Method for PCM/FM Telemetry

1. Set up the equipment as shown in Figure 2.
2. Divide the desired peak deviation by 2.4.
3. Adjust the oscillator frequency to the result found in Step 2.
4. Adjust the oscillator amplitude to the desired peak-to-peak level using the oscilloscope.
5. Set the RF generator output to a *maximum with no modulation* and center the carrier in the spectrum analyzer display.
6. Increase the RF generator modulation control slowly until the carrier disappears (or drops at least 20 dB below adjacent sidebands).
7. Substitute the modulation source for the oscillator and adjust the output level to the same peak-to-peak value as that selected for the oscillator.

The RF generator is now calibrated to the desired FM deviation. The deviation may be changed and the calibration maintained by changing the input voltage in direct ratio to the desired change in peak deviation. Do not make any additional adjustments to the RF generator modulation *controls, this will invalidate the previous calibration.*

Carrier Null Method of Subcarrier FM Telemetry

1. Set up the equipment as shown in Figure 2.
2. Divide the desired rms deviation by 2, call this f_o.
3. Adjust the oscillator frequency to f_o.
4. Adjust the rms value of the oscillator amplitude to a convenient value near the expected rms voltage of the notch noise test signal (or other baseband test signal) to be used.

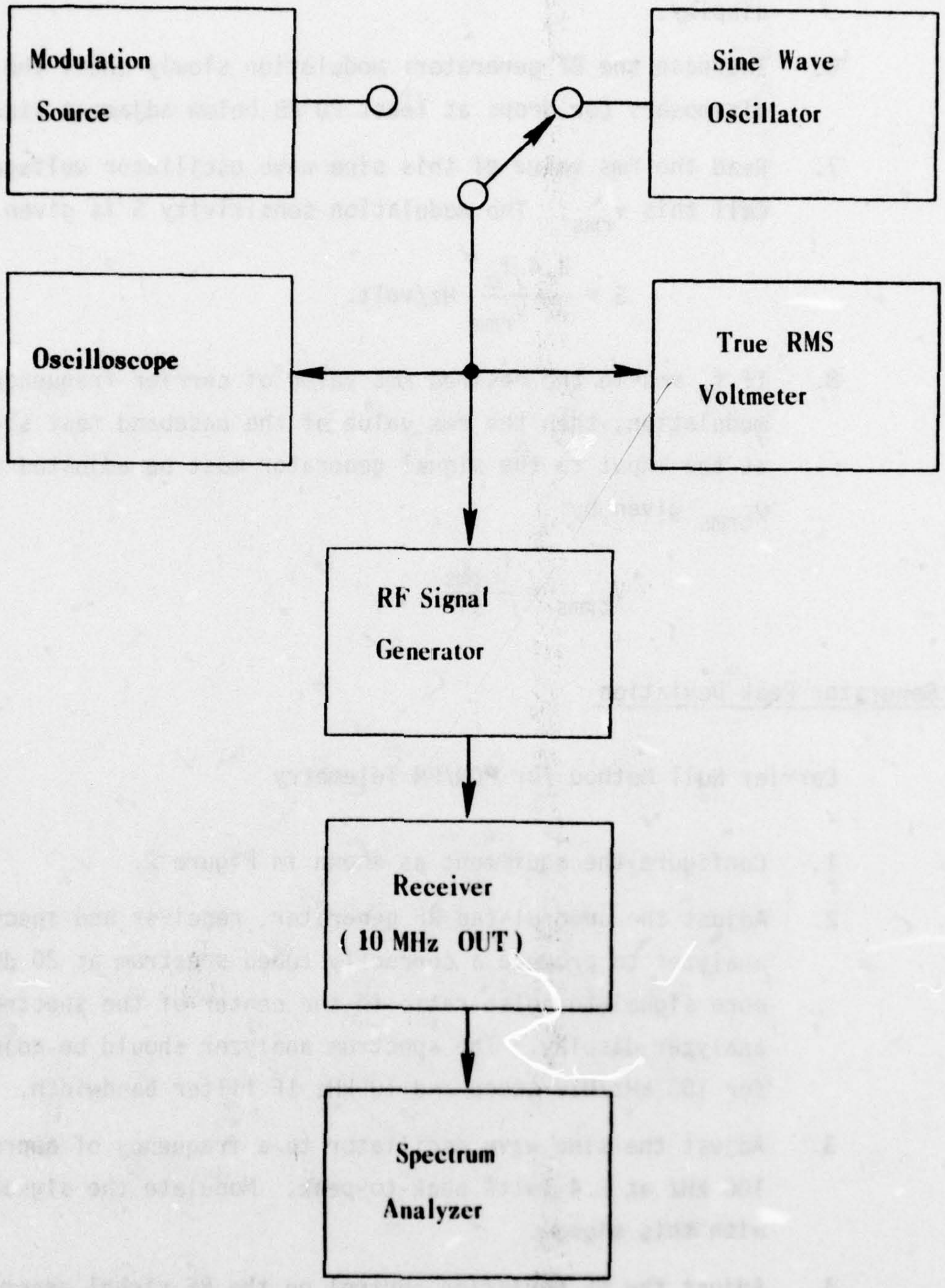


Figure 2 DEVIATION CALIBRATION EQUIPMENT CONFIGURATION

5. Set the RF generator output voltage to a maximum with CW modulation and center the carrier in the spectrum analyzer display.

6. Increase the RF generators modulation slowly until the carrier disappears (or drops at least 20 dB below adjacent sidebands).

7. Read the rms value of this sine wave oscillator voltage. Call this v_{rms}. The modulation sensitivity S is given by

$$S = \frac{2.4\ f_o}{\sqrt{2}\ v_{rms}} \text{ Hz/volt.}$$

8. If f_o rms in the desired rms value of carrier frequency modulation, then the rms value of the baseband test signal at the input to the signal generator must be adjusted to v_{trms} given by

$$V_{trms} = \frac{f_{orms}}{S}$$

PM Generator Peak Deviation

Carrier Null Method for PCM/PM Telemetry

1. Configure the equipment as shown in Figure 2.

2. Adjust the unmodulated RF generator, receiver and spectrum analyzer to produce a correctly tuned spectrum at 20 dB or more signal-to-noise ratio in the center of the spectrum analyzer display. The spectrum analyzer should be adjusted for 100 kHz/DIV sweep and 10 kHz IF filter bandwidth.

3. Adjust the sine wave oscillator to a frequency of approximately 100 kHz at 2.4 volts peak-to-peak. Modulate the signal generator with this signal.

4. Adjust the RF deviation control on the RF signal generator to produce the first carrier null, as observed on the spectrum analyzer. Do not remove the control from this setting during the remainder of the testing.

5. The RF generator is now calibrated to produce 1 radian peak deviation for 1 volt peak-to-peak input.

6. Remove the sine wave oscillator from the RF signal generator input and connect the desired modulation source.

7. Adjust the output of the modulation source to the same peak-to-peak voltage as the desired peak deviation in radians.

The RF generator is now calibrated to the desired peak PM deviation in radians. The deviation may be changed and the calibration maintained by changing the input voltage in direct ratio to the desired change in peak deviation.

Note: In all cases where a stated peak-to-peak deviation is required, the modulating voltage peak amplitude is measured using a calibrated oscilloscope. The use of a voltmeter in this case may cause considerable error due to complex wave form inputs as, for example, filtered PCM.

1.4 DEVIATION MEASUREMENT OF A TRANSMITTED FM SIGNAL

1.4.1 Theory

A receiver containing a frequency demodulator is used as a deviation meter. To provide highly accurate measurements, the display is calibrated with a signal generator whose deviation has been set by the carrier null method. Two methods of measurement are described. Peak deviation is specified for constant amplitude modulation such as PCM, PDM, PAM, etc. while rms deviation is the most accurate method of measuring complex waveform modulation such as subcarrier telemetry.

1.4.2 Test Procedure

1. Set up the equipment as shown in Figure 1.
2. Adjust the unmodulated RF generator, receiver and spectrum analyzer to produce a correctly tuned spectrum at 20 dB or more signal-to-noise ratio in the center of the spectrum analyzer display. The spectrum analyzer should be adjusted for 100 kHz per division sweep and 10 kHz IF filter bandwidth.
3. Adjust the sine wave oscillator to a frequency of 83 kHz and 1.0 volts rms as indicated on the true rms meter. Modulate the RF generator with this signal.
4. Adjust the RF deviation control on the signal generator to produce the first carrier null (at least 20 dB below adjacent sidebands), as observed on the spectrum analyzer. This gives a deviation sensitivity of $S = 200/\sqrt{2} = 141$ kHz/volt.
5. The RF generator is now calibrated to produce 200 kHz peak deviation since the input is $\sqrt{2}$ volts peak. This signal is now used to calibrate the oscilloscope and true rms voltmeter which are connected to monitor the receiver video output.

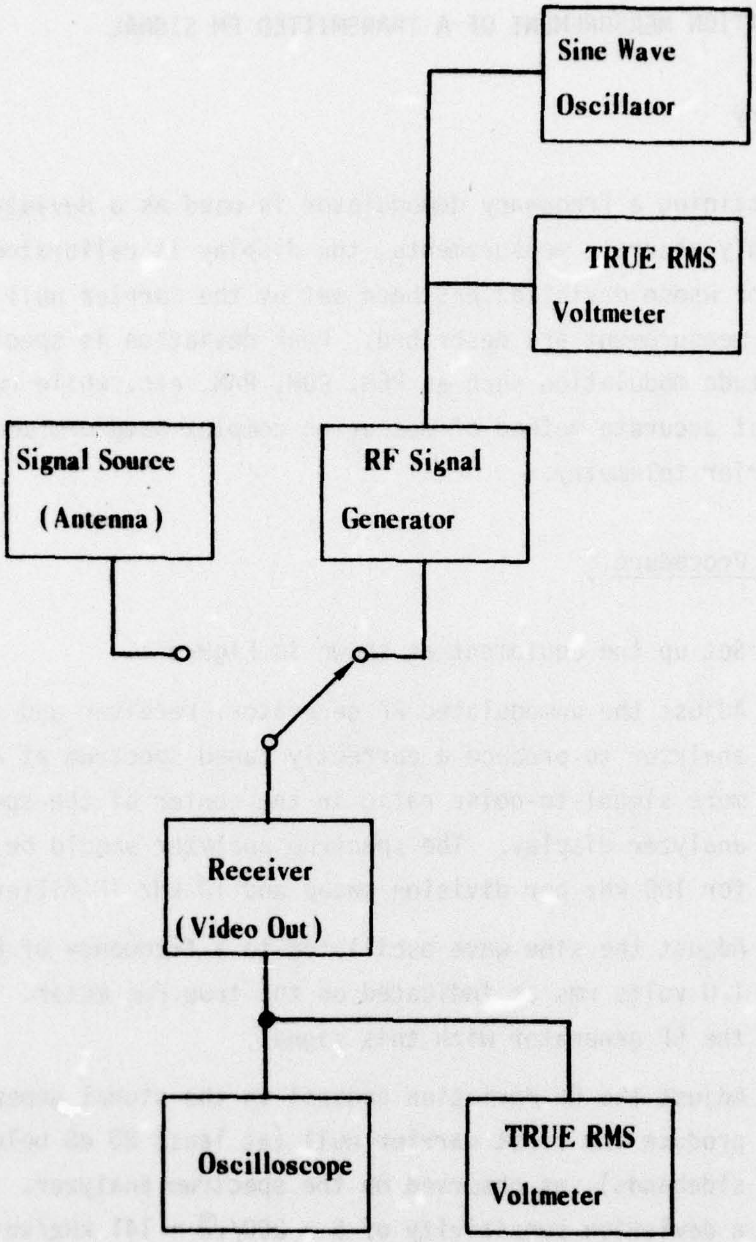


Figure 1 DEVIATION CALIBRATION EQUIPMENT CONFIGURATION

6. Peak Deviation. Adjust the receiver video output filter to the highest filter setting available and adjust the output level to control to produce a 2 volt peak-to-peak deflection on the oscilloscope. The oscilloscope and receiver are now calibrated to display 200 kHz peak deviation per volt deflection on the oscilloscope display, i.e., a sensitivity of 200 kHz/volt.

7. rms Deviation. The true rms voltmeter should indicate 0.707 volts rms and is calibrated to indicate 200 kHz rms deviation per rms volt.

8. Remove the signal generator from the receiver input and patch the receiver to the antenna. The unknown deviation may be read directly from the oscilloscope for peak deviation or from the voltmeter for rms deviation.

Note: These calibrations are accurate only over the linear range of the receiver discriminator and video output amplifier. If the indicated deviation exceeds the receiver discriminator specifications, or the output VU meter indicates above + 3 dB, it will be necessary to recalibrate the system using either a wide band discriminator or at a lower video output level.

1.5 RF BANDWIDTH MEASUREMENT

1.5.1 Theory

This brief section is written to aide in the reporting of recurring errors by range users in setting transmitter deviation. Deviation measurement alone does not provide the impact of the actual bandwidth required for receiving, recording and relaying a given data link. Section 4 (Range Planning) describes data formats and link models used by operations planners at SAMTEC. In most cases, these models work very well becuase the data format and carrier deviation provided by the range user are reasonably accurate. Unfortunately, many users simply specify maximum deviation capability of the transmitter. In response to this lack of information, the range has implemented a system of collecting spectrum photographs during prelaunch checks. Late changes to the support configuration are then made as required.

The following procedure is not written for the planner but for the Operations Controller who must make a real-time decision on where a data transmission problem lies. A spectrum analyzer is used to measure the actual bandwidth of the transmitted signal. If the actual bandwidth is less than the 3 dB bandwidth of receiver IF filters, microwave channel filters, etc., any transmission problem due to bandwidth limiting can be systematically isolated. On the other hand, excessive transmitter deviation is also quickly pinpointed. Of course, from the point of view of required bandwidth, considerations of Doppler shift, carrier frequency instability, tuning error, etc. must be taken into account. As a general rule, the actual signal bandwidth should be 100 kHz less than receiver IF and microwave channel filters.

The following definitions of bandwidth do not conform to the definition of bandwidth which is 60 dB down from the unmodulated carrier as measured in a 3 kHz spectrum analyzer IF bandwidth as stated in IRIG 106-73, Telemetry Standards. The IRIG (Inter-Range Instrumentation Group) definition is intended to specify maximum channel bandwidth to prevent adjacent channel interference. In this case, an unmodulated carrier cannot be provided for reference. In addition, there are several unique data transmission formats

on test vehicles that exceed IRIG guidelines. See Reference 1 for spectrum photographs of typical non-IRIG formats supported by the range. Section 4 of this handbook contains some examples from Reference 1.

The method described below uses a spectrum analyzer to determine the minus 40 dB points of a transmitted signal. The minus 40 dB level is measured relative to the maximum of the modulated signal, i.e., does not include the unmodulated carrier component. Examples of PCM/FM, PCM/PM and FM/FM are shown in Figures 1 through 3. Note that the unmodulated carrier component of the PCM/PM is not used as a reference in Figure 2. The only known exception to this measurement method is the SGLS (Space Ground Link Subsystem) format. Because the SGLS carrier deviation is narrowband PM, only the first sideband of each subcarrier is significant. The measurement method can be applied to SGLS formats as shown in Figure 4 by selecting the maximum of the modulated signal to be the maximum of the highest frequency subcarrier.

The minus 40 dB points have been selected as the required bandwidth based on the results of monitoring over forty data formats supported by SAMTEC during the past five years. This bandwidth will produce PCM data quality of $P_e < 1 \times 10^{-6}$ or FM/FM data quality of static linearity error of less than one percent (dynamic distortion error in terms of noise power ratio of greater than 30 dB) near the minimum theoretical signal-to-noise ratio. The monitoring program has shown that the minus 30 dB point bandwidth will also support data transmission but at a degraded data quality level. Narrower bandwidths produce intolerable data degradation.

Reference

1. Report Number P100-75-18, Telemetry Planning Data Vandenberg AFB, California: FEC Systems Analysis Directorate, 20 March 1975.

1.5.2 Test Procedure

1. Connect the spectrum analyzer to the receiver linear 10 MHz IF output as shown in Figure 5. The spectrum analyzer may also be connected directly to the multicoupler output if a high frequency tuning unit is available for the analyzer.

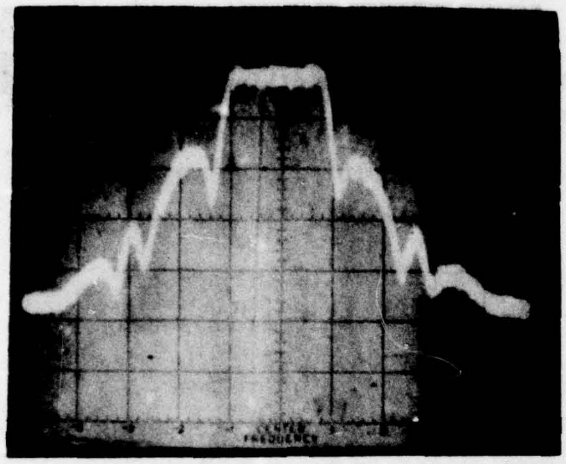
2. Select a spectrum analyzer IF bandwidth of 10 kHz and a horizontal scale to display the desired spectrum as shown in the examples of Figures 1 through 4.

3. Tune the analyzer to place the RF spectrum in the center of the display and adjust the vernier reference control to place the highest modulated signal component at a convenient mark on the graticule.

4. Determine the point at 40 dB below the highest modulated signal component.

5. Record the frequency difference between the points of step 4 and record this difference as the RF bandwidth.

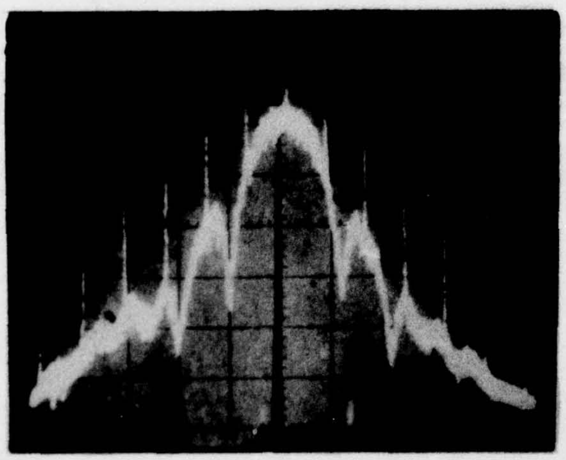
Note: Care must be taken to ensure that the receiver IF is wide enough to pass the RF signal without distortion. If the 40 dB points cannot be determined, or the receiver mission IF filter is not 100 kHz or more than the RF bandwidth, notify the Operations Control Center (OCC).



(1) Analyzer Settings:
  (a) Vertical Scale = 10 dBm/cm
  (b) Horizontal Scale = 100 kHz/cm
  (c) IF Bandwidth = 10 kHz
  (d) Video Bandwidth = 100 Hz

(2) RF Bandwidth = 850 kHz
  (measured at 40 dB points)

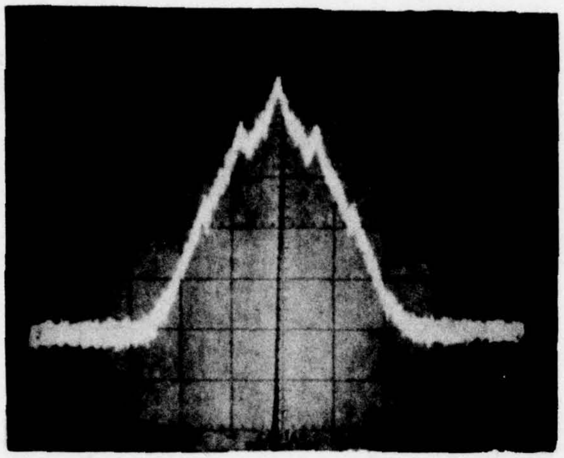
Figure 1 Spectrum Photograph of PCM/FM



(1) Analyzer Settings:
  (a) Vertical Scale = 10 dB/cm
  (b) Horizontal Scale = 200 kHz/cm
  (c) IF Bandwidth = 10 kHz
  (d) Video Bandwidth = 100 Hz

(2) RF Bandwidth = 800 kHz
  (measured at 40 dB points)

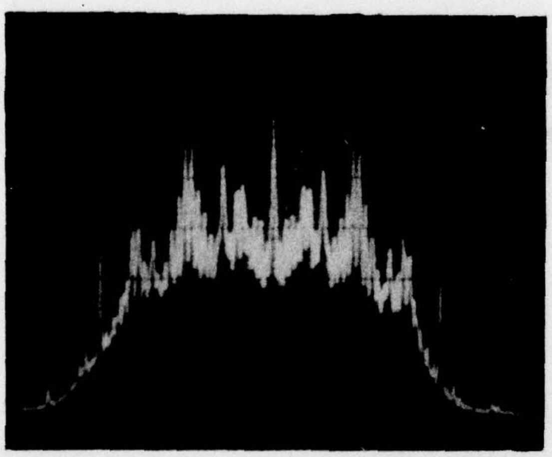
Figure 2 Spectrum Photograph of PCM/PM



(1) Analyzer Settings:
(a) Vertical Scale = 10 dB/cm
(b) Horizontal Scale = 200 kHz/cm
(c) IF Bandwidth = 10 kHz
(d) Video Bandwidth = 100 Hz

(2) RF Bandwidth = 800 kHz
(measured at 40 dB points)

Figure 3 Spectrum Photograph of FM/FM



(1) Analyzer Settings:
(a) Vertical Scale = 10 dB/cm
(b) Horizontal Scale = 500 kHz/cm
(c) IF Bandwidth = 10 kHz
(d) Video Bandwidth = 100 Hz

(2) RF Bandwidth = 3.5 MHz
(measured at 40 dB points)

Figure 4 Spectrum Photograph of SGLS Format

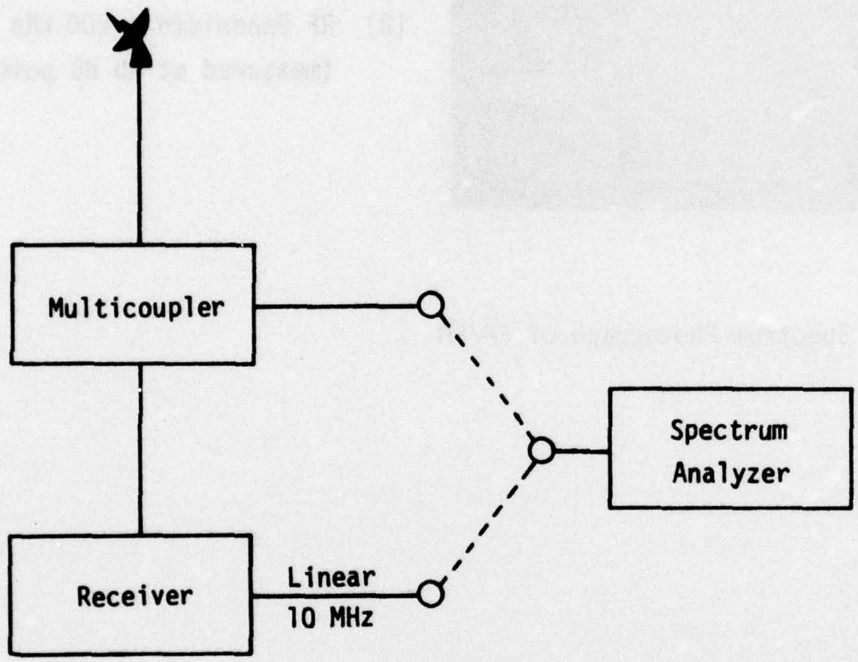


FIGURE 5

RF BANDWIDTH MEASUREMENT CONFIGURATION

1.6 BIT ERROR RATE TEST

One method of determining the performance of a PCM telemetry subsystem, or the data degradation encountered in PCM recording and data transmission systems, is the Bit Error Rate (BER) Test. The purpose of this test is to measure bit errors at the PCM bit synchronizer while varying the signal-to-noise ratio (SNR) at the input to the receiving system. Test results provide a means of system comparison between PCM systems and the theoretical results as well as a quantitative measure for use in link calculations. Results may also provide a Go-No-Go criteria for system operational readiness and may be used in the validation of playback stations before reduction of recorded data (refer to Section 3 Data Processing procedure 3.1, Front End Certification). The system measurements are summarized in a plot of bit error versus input signal-to-noise ratio as measured in the receiver second IF.

The present pseudo-noise (PN) bit sequence used for these tests offers many advantages not previously available. The primary advantage is the synchronization of the PCM receiver on any eleven bits of the transmitted code. Synchronization is thus easily and automatically made even for transmission delays longer than an entire 2047 bit frame of data. The test set receiver regenerates the same code as the transmitter and performs a bit by bit comparison to determine if any errors are caused by the transmission link (normally an antenna, receiver, diversity combiner, microwave relay systems and bit synchronizer).

REFERENCES

1. Panter, P.F. Modulation, Noise and Spectral Analysis, New York: McGraw-Hill Book Company, 1969.
2. IRIG Document 118-73, Test Methods for Telemetry Systems and Subsystems. Revised July 1975.
3. Taub and Schilling, "Principles of Communication Systems" McGraw-Hill, New York, 1971 pages 323-335.

4. J. J. Hayes, et al "Wideband PCM-FM Bit Error Probability Using Discriminator Detection" ITC-1968 Proceedings page 233.

See Also

5. F. L. Lim and Q. C. Tham "On the Threshold Performance of a PCM/FM Receiver" IEEE Transactions on Communication May (1974) page 726.

6. Q. C. Tham and L. C. Lim "Optimal and Suboptimal Performance of a PCM/FM Communication System" IEEE Transactions on Aerospace and Electronic Systems, July (1975) page 575.

1.6.1 Theory

The following theory and formulas are provided to help in understanding the test data for PCM/PM and PCM/FM. Generally, in PCM/PM, the PM carrier is detected coherently by a narrow phase-lock loop and the bits are detected by a matched filter or equivalent. In this case, the BER is a function of E_b/N_o where

$$E_b = \frac{S_m}{f_b} \qquad (1)$$

where

E_b = modulation energy per data bit

S_m = power in the carrier modulation

f_b = data bit rate

N_o = noise spectral power density (one sided) in the IF.

In other words, the BER is independent of IF bandwidth provided it is wide enough to pass the modulated carrier with negligible distortion. Also, with matched filter bit detection, biphase and NRZ perform the same at the same data bit rate. However, E_b/N_o can be written as

$$\frac{E_b}{N_o} = \frac{S_m}{f_b\, N_o} = \text{SNR} \qquad (2)$$

stated in an IF bandwidth equal to the bit rate. Also, assuming the bit stream is nearly rectangular,

$$S_m \doteq S \sin^2 \Delta \tag{3}$$

where S = total carrier power

and Δ = peak phase modulation.

Generally, S_m is almost one dB less than S except in the case of $\pm 90°$ modulation for which $S = S_m$. Note also that if the data bit rate is doubled, then the power must be doubled to produce the same E_b.

In PCM/FM, the carrier is detected by a limiter/discriminator which is a complicated non-linear device operating in the full IF bandwidth. One way of modeling the noise output of a discriminator is to break it into two components: "pop noise" (somestimes called clicks) and smooth fluctuation noise. The pops are sharp pulses frequently extending to the band edge. When the IF bandwidth is several times greater than the bit rate, the pops are the principal cause of bit errors. For a given peak deviation, the pop rate is a decreasing exponential function of ρ, the SNR in the IF. Thus, when the BER is plotted against ρ, the curves are almost independent of IF bandwidth, provided it is several times f_b. Thus the BER, increases exponentially with increasing bandwidth. Therefore, in PCM/FM, the signal power efficiency is improved by degreasing the IF bandwidth. The optimum IF bandwidth equals f_b at which point the optimum peak-to-peak deviation is approximately $0.7f_b$.

Therefore in PCM/FM the carrier discriminator must operate in an IF bandwidth sufficiently wide to include the necessary modulation side bands. It has been found that the optimum IF bandwidth is equal to the bit rate, f_b[4]. The corresponding optimum deviation is 0.7 f_b peak-to-peak. The video bandwidth should be about 0.5 f_b (including the additional filtering in the bit detector). The bit error probability, experimentally determined, under these optimum conditions is shown in Figure 1 plotted as points against the predetection signal-to-noise ratio in a bandwidth equal to the bit rate[4].

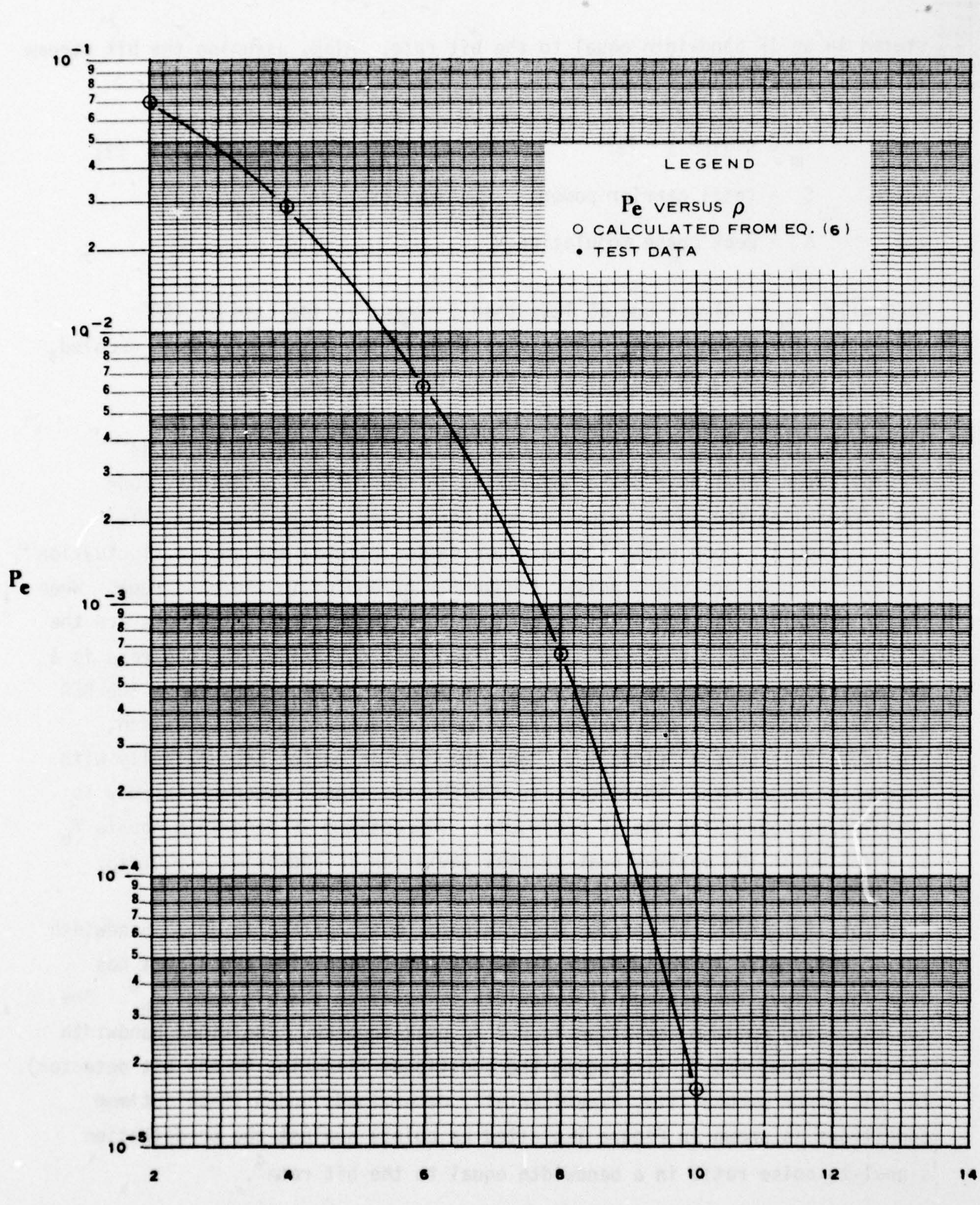

LEGEND
Pe VERSUS ρ
O CALCULATED FROM EQ. (6)
• TEST DATA
10^-1
10^-2
10^-3
10^-4
10^-5
Pe
2
4
6
8
10
12
14
db ρ

Figure 1

Frequently, it is necessary to operate in a bandwidth greater than the bit rate because of doppler shift, frequency drift and other operational conditions. In the following a simplified and approximate procedure is given for estimating bit error probability in cases where the IF bandwidth is greater than several times the bit rate. This procedure is based on the "pop" noise (sometimes called clicks or spikes) which appears near threshold in the output of a discriminator(1). In general, the noise output of a discriminator can be modeled as a superposition of fluctuation noise (smooth hiss) and pop noise. When the IF bandwidth is several times the video bandwidth, F_c, the video output is the response of the video filter to a very sharp pulse (delta function). To simplify the analysis, assume that the video filter is ideal low pass with vertical cutoff. Then the height of the pops in the video output is

$$h = 2F_c \text{ Hz} \tag{4}$$

where the output is expressed in terms of equivalent carrier deviation.* If $h > f_o$ where f_o = peak deviation in Hz due to the bit stream, it is assumed that a bit error occurs. If the carrier is deviated f_o, then, approximately, the number of pops N- receiving per second is

$$N- \simeq f_o e^{-\rho} \text{ per second} \tag{5}$$

where ρ = SNR in the predetection (IF) bandwidth. When f_o is positive the pops are negative and vice versa. Thus the pops are in the opposite direction of the bit pulses and if $h > f_o$, it is assumed that each pop causes an error. Call this Case I.

Thus the bit error probability, due to pops, is given approximately by

$$\text{Case I:} \qquad P_e \simeq \frac{N-}{f_b} = \frac{N+}{f_b} = \frac{f_o e^{-\rho}}{f_b} \tag{6}$$

*For example, if the discriminator sensitivity is 1 volt/100 KHz then 1 volt in the output corresponds to 100 KHz carrier deviation.

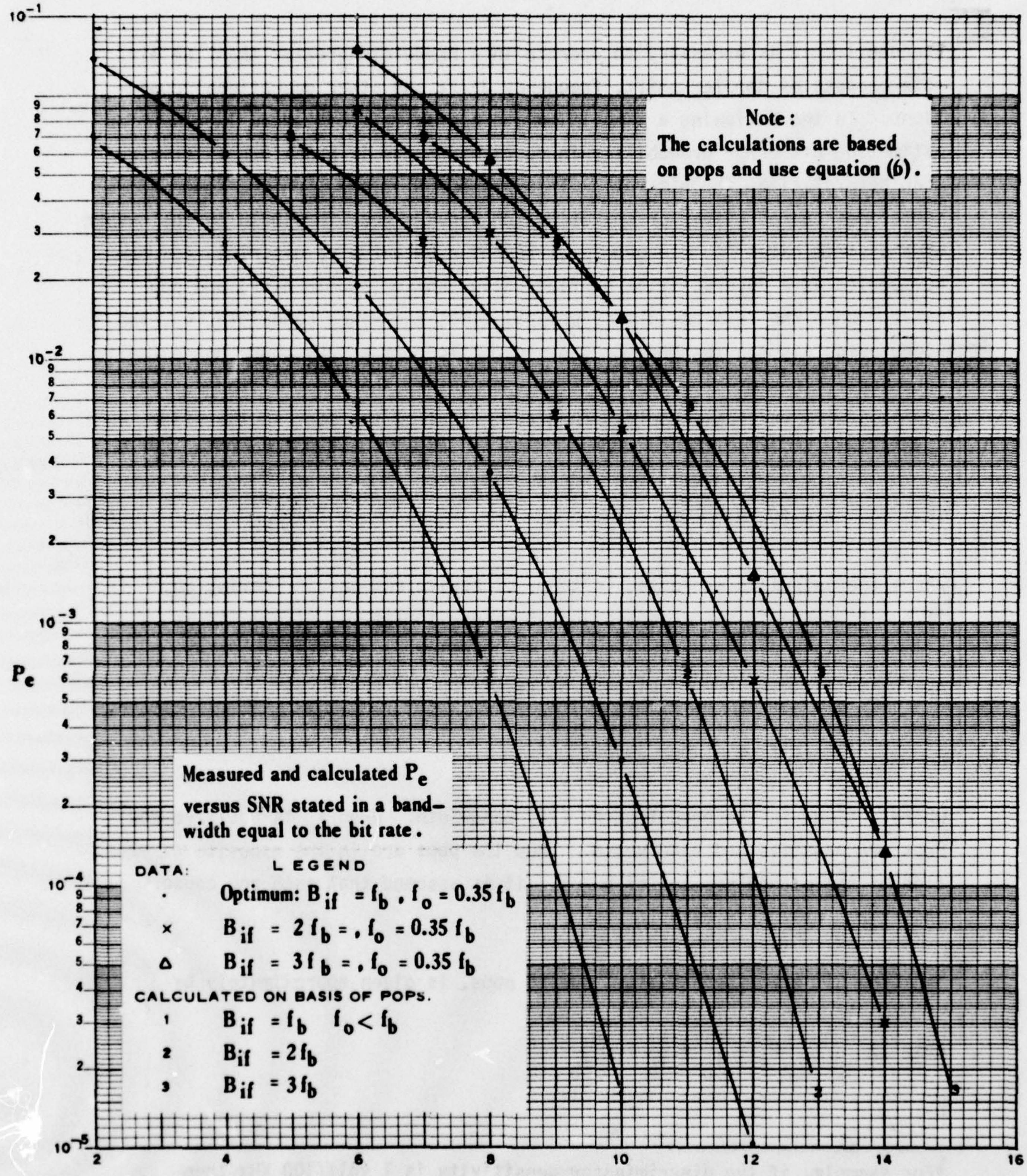

Note:
The calculations are based on pops and use equation (6).
Measured and calculated P_e versus SNR stated in a bandwidth equal to the bit rate.
DATA:
LEGEND
· Optimum: $B_{if} = f_b$, $f_o = 0.35 f_b$
× $B_{if} = 2 f_b =$, $f_o = 0.35 f_b$
Δ $B_{if} = 3 f_b =$, $f_o = 0.35 f_b$
CALCULATED ON BASIS OF POPS.
1 $B_{if} = f_b$ $f_o < f_b$
2 $B_{if} = 2 f_b$
3 $B_{if} = 3 f_b$
P_e
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
2
4
6
8
10
12
14
16
db SNR in f_b

Figure 2

To see how well this approximation works, the bit error predictability is calculated from equation (6). Figure 2 shows P_e test data for three predetection bandwidths namely $B_{IF} = f_b$, $2f_b$ and $3f_b$ for the case $f_o = 0.35\ f_b{}^4$. The P_e are plotted versus SNR stated in a predetection bandwidth $= f_b$. The relation is

$$(SNR)f_b = \frac{B_{IF}}{f_b}\ \rho \tag{7}$$

or in dB

$$dB(SNR)f_b = dB(\rho) + dB(B_{IF}/f_b) \tag{8}$$

The advantage of using $(SNR)f_b$ is that, if f_b is held constant, it is proportional to signal power independent of predetection bandwidth, B_{IF}. The numbered points in Figure 2 are calculated from equation (6). Note that the agreement is good for $B_{IF} = 3_b$. It is less good for $B_{IF} = 2f_b$ and worst for the optimum case $B_{IF} = f_b$. The reason is that in these cases fluctuation noise is also important in determining p_e. It is evident that for $B_{IF} > 3f_b$, the effects of fluctuation noise can be neglected. Figure 2 shows P_e calculated from equation (6) versus ρ the SNR in the predetection bandwidth, B_{IF}, compared to test data. Note that if $B_{IF} > 3f_b$, P_e depends approximately on ρ only.

Now suppose that $2F_c < f_o < 4F_c$ then at least two pops are required in a bit period to cause an error. Call this Case II. In this case, the video filter adds the two pulses to give an output $> f_o$ thus causing an error.

Using the Poisson distribution, the bit error predictability in this case is given approximately by

$$\text{Case II:} \qquad P_e \simeq \frac{1}{2}\left(\frac{f_o e^{-\rho}}{f_b}\right)^2 e^{-\left(\frac{f_o e^{-\rho}}{f_b}\right)} \simeq \frac{1}{2}\left(\frac{f_o e^{-\rho}}{f_b}\right)^2 \tag{9}$$

the last approximation being valid for the practical ranges of parameters involved.

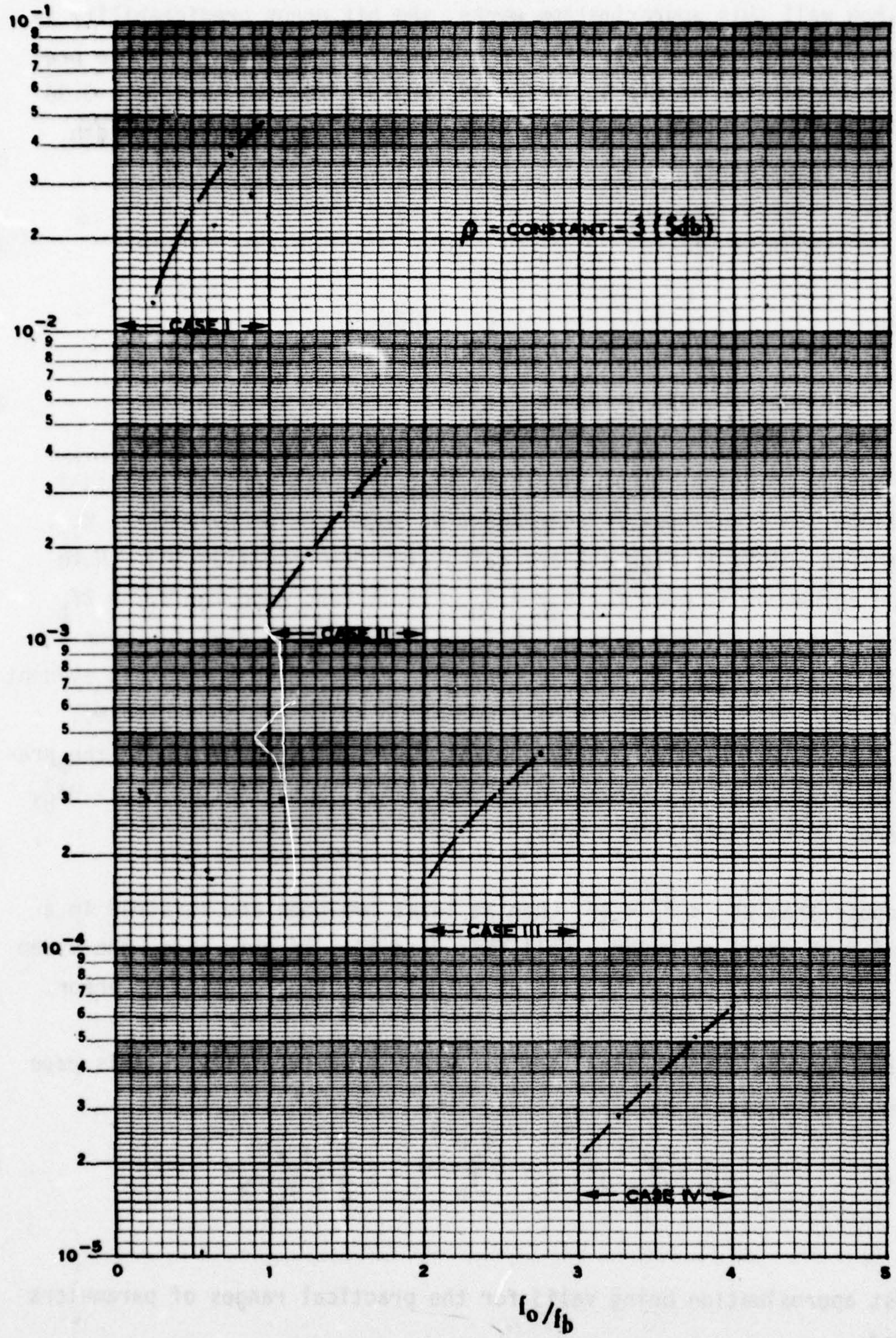


Figure 3 Calculations based on Pops in P_e versus f_o/f_b (deviation ratio) with ρ = constant = 3 (5db). It is assumed that $B_{if} > 3\ f_o$ and, in addition, is great enough to accomodate the modulation side bands.

If $4F_c$ < to < $6F_c$, then at least three pops are required in a bit period to cause an error. Call this Case III. In this case, the Poisson distribution gives, approximately:

Case III: $$P_e \simeq \frac{1}{6}\left(\frac{f_o e^{-\rho}}{f_b}\right)^3 \qquad (10)$$

and so on.

For purposes of illustrating the above equation, suppose $F_c = 0.5\ f_b$. Also hold ρ constant. In Figure 3, P_e calculated from the above approximate expressions is plotted against f_o/f_b for $\rho = 3$ (5 dB). The ratio f_o/f_b may be considered as the deviation ratio. It is assumed that $B_{IF} > 3f_b$ so that pop noise causes most of the bit errors.

In real life, the sharp drops in Figure 3 are rounded off because the pops vary somewhat in height. The upward break indicated for small f_o/f_b is due to fluctuation noise.

There are several important conclusions to be drawn from Figure 3. One is that, if for whatever reason, $B_{IF} >> f_b$, then f_o/f_b should be made as large as possible consistent with B_{IF}.* Also f_o/f_b should be chosen near the lowest minimum possible in Figure 3. Another important conclusion is that the P_e in Figure 3 is considerably higher than for the optimum conditions of $B_{IF} \simeq f_b$ and $f_o/f_b \simeq 0.35$. To illustrate this, suppose f_o is held constant.

Then f_b is inversely proportional to the deviation ratio f_o/f_b so that the optimum predetection bandwidth $B_{IF} \simeq f_b$ is inversely proportional to f_o/f_b. Let the P_e at $f_o/f_b = 0.35$ in Figure 5 be considered approximately optimum for $\rho = 3$ (5 dB). Then optimum P_e for the various values of f_o/f_b can be estimated from the optimum curve in Figure 2 by adding to the 5 dB ($\rho = 3$) the quantity

$$10\ [\log_{10}(f_o/f_b) - \log_{10} 0.35] = 10\log_{10}(f_o/f_b) + 4.5 \qquad (11)$$

*Roughly, $B_{IF} \simeq 2f_o + 2f_b$ (Carson's rule). With a given B_{IF}, f_o/f_b can be adjusted for minimum P_e.

This gives Table 1.

Table 1

Optimum P_e Versus P_e from Figure 3

f_o/f_b	$10 \log_{10}(\frac{f_o}{f_b}) + 4.5$	Equivalent SNR in f_b	Optimum P_e	P_e - Fig 3
0.35	0	5	$\simeq 10^{-2}$	$\simeq 10^{-2}$
1.0	4.5	9.5	6×10^{-4}	1.3×10^{-3}
2.0	7.5	12.5	4×10^{-6}	1.6×10^{-4}
3.0	9.5	14.5	10^{-6}	2×10^{-5}

It follows from this discussion that a wide variation in BER testing results may be observed if the method of testing and reporting is not defined or standardized. It is recommended that BER be plotted as a function of the IF SNR refined to an IF bandwidth equal to the bit rate, f_b. For checking purposes, it may also be useful to plot the PCM/FM results as a function of IF SNR measured in the IF bandwidth used for the tests. To compute SNR in a bandwidth equal to the bit rate f_b, use the formula:

$$(SNR)_{fb} = \frac{B_n}{f_b} (SNR)B_n \qquad (12)$$

where

B_n = noise bandwidth in which $(SN)B_n$ is measured (3dB bandwidth is generally a good approximation).

Or, in dB

$$(SNR)_{fb} \text{ dB} = (SNR)B_n \text{ dB} + 10 \log_{10} \frac{B_n}{f_b} \qquad (13)$$

Figures 4 and 5 are bit error rate plots which may be used for NRZ and biphase data. These plots are not theoretical plots, they are bit error rate plots which should be available at any SAMTEC telemetry system. If a tape recorder is used as part of the system, a maximum 1 dB may be added to SNR.

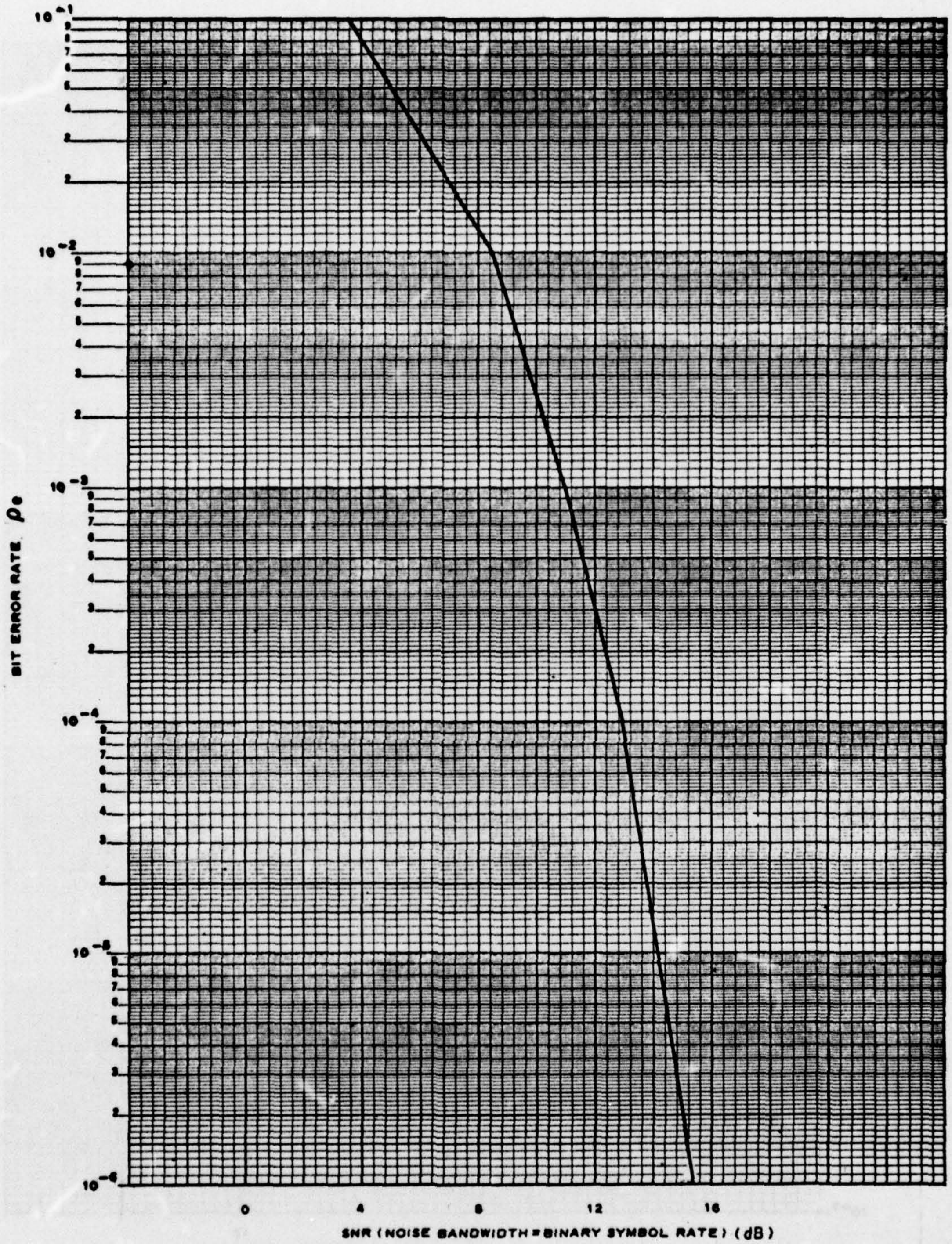


FIGURE 4 BI-ϕ PCM-PM BIT ERROR RATE

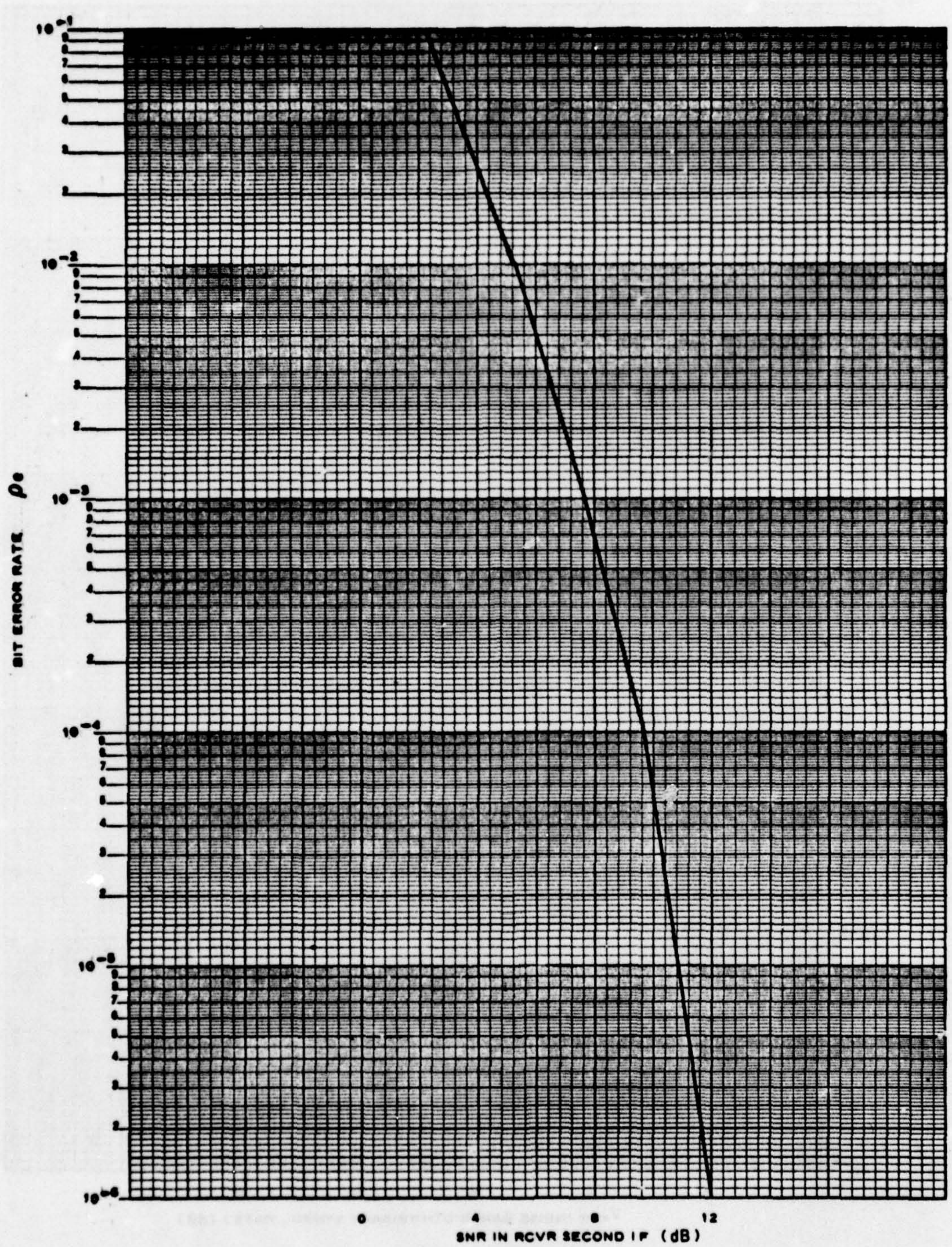


FIGURE 5 PCM-FM BIT ERROR RATE

1.6.2 Test Procedure

1. Configure the system as shown in Figure 6 (typical SAMTEC Operations Directive (OD) configuration) for the telemetry system to be tested. Configure the microwave system for the required bandwidth for each channel.

2. The RDF configures the bit error rate test set and PCM synchronizer to receive a pseudo random pattern at the bit rate and the code for the configuration to be tested. Select the appropriate pre-d frequency on the pre-detection receivers.

3. TRS and Pillar Point set up the bit error rate test set to transmit a pseudo random pattern at the bit rate and the code for the configuration to be tested. Position the antenna to cold sky.

4. Select the receiver IF and pre-d frequency as specified in the launch OD. Tune the receiver to the appropriate link frequency to be measured.

5. Set up the signal generator to CW and transmit the appropriate RF frequency.

6. Connect a power meter to the 10 MHz linear IF output of the receiver to be tested.

7. Reduce the signal generator output to the minimum setting on the dial and measure the IF power.

8. Switch the receiver to manual bias and adjust the bias to give the same IF power measured in Step 7 above.

9. Raise the signal generator output until a 3db increase in power is measured in the IF. Note the dial setting.

10. To determine that (with the AGC bias used) the IF is linear at least over the range 0-3dB, check to see that the following table is verified:

Ps	IF Output Power	dB increase (relative to N)
Minimum setting	N	-
P_{si}	2N	3dB
2 P_{si}	3N	4.77dB
3 P_{si}	4N	6dB

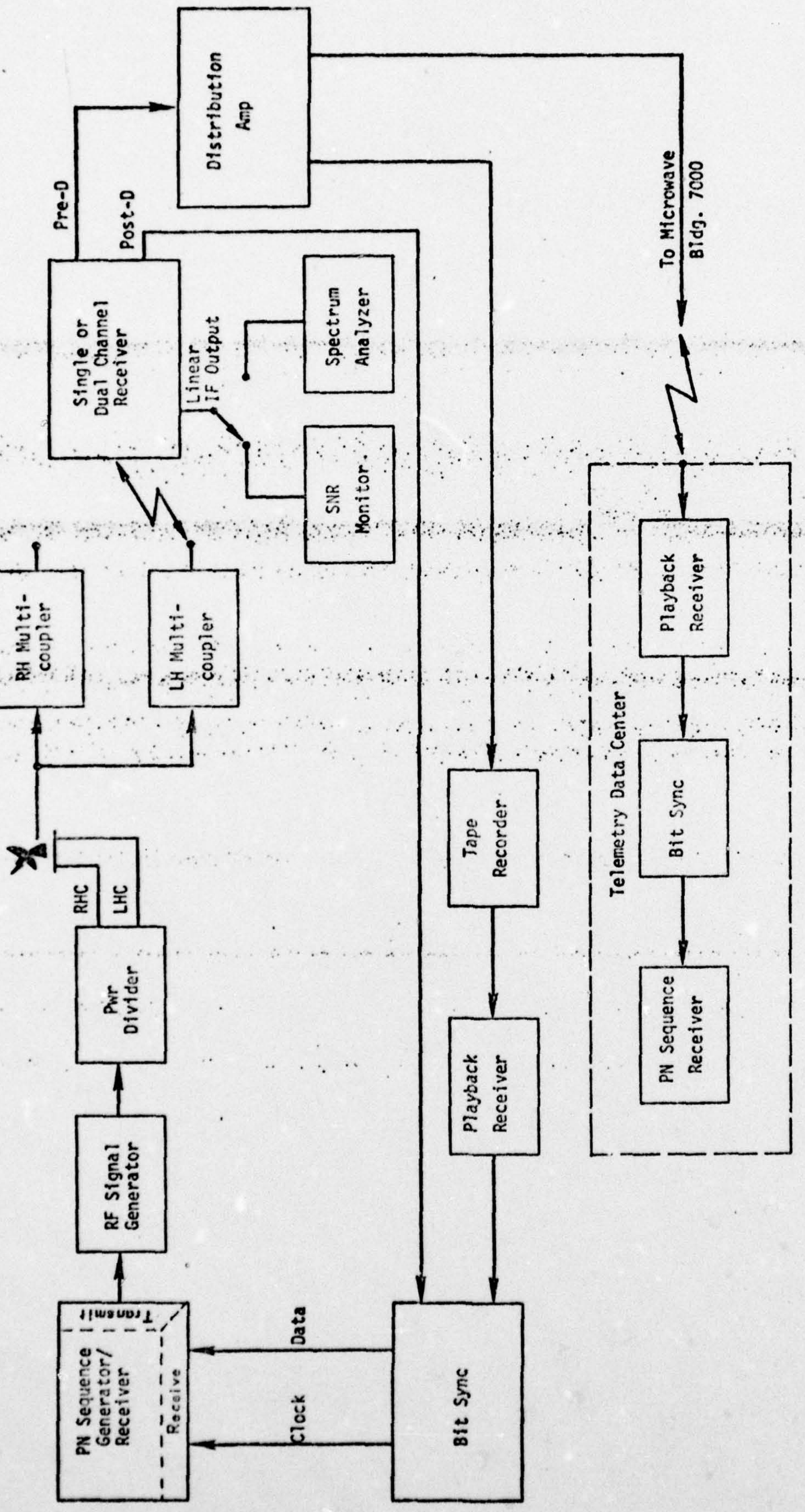


FIGURE 3 BIT ERROR RATE TESTING

where

P_s = signal generator output power. P_{si} is the system noise with no single. When $P_s = P_{si}$,

SNR = 1 or 0dB. In dBm, 2 P_{si} is P_{si} (dBm) + 3 dB, 3P_{si} is P_{si} (dBm) + 4.77 dB. If the table is not verified to within a few tenths of a dB, change the bias until a satisfactory operating point for the test is found.

NOTE: This linearity check, in terms of power meter readings of the receiver IF and of the signal generator dial, is simply to observe that the power meter reading increases 1.8 dB for a 3 dB change or increase on the signal generator dial after step 9. (i.e., the initial 3 dB increase in IF power was made). Another 1.2 dB increase on the power meter should be observed when the signal generator output level is increased by 1.8 dB. Accuracies of $\pm$0.3 dB are acceptable because the meter and generator dial readings contribute the major errors.

11. Record the power at the input to the pre-amp.

NOTE: This reading represents zero dB S/N ratio in the IF and the signal generator dial reading should be the same as that obtained during solar calibration of the RF frequency under test.

12. Return the receiver to the AGC mode.

13. Modulate the signal generator with a PCM signal from the bit error rate test set. Select the appropriate type of modulation and adjust the modulation level, bit rate, and code specified in the OD.

14. Raise the signal generator output 14 dB for FM modulation or 10 dB for PM modulation as read on the generator dial. When a combiner is used, the signal generator is raised 13 dB for FM and 9 dB for PM modulation.

NOTE: These figures are for zero to 1 Mbs PCM/NRZ data and zero zero to 500 kbs PCM/Bi-Ø data.

15. Verify that the bit error rate test set at the RDF indicates an "In-Sync" condition. Log the error count as read on the error counter. If the error count is zero or varies between zero and one, the results can be considered acceptable. If an error rate greater than 1 in 10^6 bits occurs, then the system fails the test and corrective action must be taken.

16. Decrease the signal generator level to the setting obtained in Step 9 (receiver IF SNR = zero dB). Note that the bit error rate test set at the REF indicates errors, raise the signal generator level to establish the S/N ratio required in Step 14. Note that the RDF receivers recapture properly and the error count read in Step 15 is obtained.

17. Repeat Steps 1 through 14 for each link to be supported in DC in real-time.

1.7 DIVERSITY COMBINER TEST

In this test, a special test set is used to produce RF signal fades by phase cancellation. Two separate channels are provided to simulate Right Hand Circular (RCP) and Left Hand Circular(LCP) polarized signals. The channels fade alternately but one is always available so that a perfect combiner can produce error free data by selecting the best receiver data. The rate of alternate channel fading is slowly increased until the combiner can no longer select fast enough. Data degradation, as monitored by BER, indicates when the combiner selection speed is exceeded.

This test technique devleoped for SAMTEC has been adopted by other ranges and has been accepted by the IRIG Telemetry Working Group for publishing in IRIG Document 118-73. References include:

1. Report P100-72-27, Diversity Combiner Test Program, Vandenberg AFB, California: FEC Systems Performance Analysis Directorate, 1972.

2. Report P100-72-45, Diversity Combiner Test Program, Part II. Vandenberg AFB, California: FEC Systems Performance Analysis Directorate, 1972.

3. IRIG Document 118-73, Test Methods for Telemetry Systems and Subsystems. Revised July 1975

1.7.1 Theory

Polarization diversity combining is commonly used at tracking ranges to ensure signal recovery from a maneuvering target. Many studies were reviewed to determine the causes of signal fades during special cases such as transmission through a missile flame due to low aspect angles, reentry plasma interference, and multipath interference encountered on low altitude aircraft flight tests over water. It was concluded that all of the signal fades could be classified as phase cancellation due to multipath interference. The studies showed that generally the fades on one polarization normally do not occur at the same time as the fades on the other polarization. Therefore, a combiner with rapid selection capability could recover higher quality data from the two polarization channels. References 1 and 2 describe a test program where the actual fade rates were measured during interference periods.

A test set design was devised by Dr. M. H. Nichols, FEC consultant, to simulate the fades or signal transients. SAMTEC receivers and combiners were optimized and tested using the test set. Improvements in flight test data confirmed the validity of the test method. The results of the test program are summarized in Reference 3. The IRIG Telemetry Group has also adopted this test method and published procedures in Reference 3.

Combiner testing is conducted in two parts - under quasi-steady state conditions and under dynamic or signal fade conditions. A typical test configuration is shown in Figure 1. A bit error rate (BER) versus receiver IF signal-to-noise ratio (SNR) set of measurements is made with no signal fades. This data will normally indicate a 2.0 to 2.5 dB improvement in SNR when combining as opposed to a single channel from the receiver when both receiver channels receive the same signal. Different levels to each of the receiver channels are used to check the combining ratio but usually are run only for equipment acceptance testing. The dynamic fade rate tests measure the selection speed of the combiner by causing a signal fade on one channel then the other but never both at the same time. With no fades, the RF signal level is set to obtain a BER of 1×10^{-5} on a single receiver channel. The combiner will show zero errors until fading is initiated. The combier will maintain the single channel BER of 1×10^{-5} as the fade frequency is increased until an abrupt "breakpoint" occurs. Virtually no data is obtained above the "breakpoint" frequency.

<u>Simulation of Transients with a Test Set</u> - It was assumed that the mission signal fades could be simulated by phase cancellation. The test set shown in Figure 1 provides fades in excess of 30 dB, and simultaneous 180 degree phase changes as described below. Referring to Figure 1, the S-band signal generator is modulated by a PN (pseudonoise) sequence PCM serial data stream at deviations and bit rates used on the major missile programs. The combiner test set then simulates the RF signal perturbations caused by the transmission path. The working principles of the combiner test set are:

1. The RF signal is split by a 50 ohm termination power divider into two identical, coherent signals. The two signals can be thought of as Right Hand Circular (RHC) and Left Hand Circular (LHC).

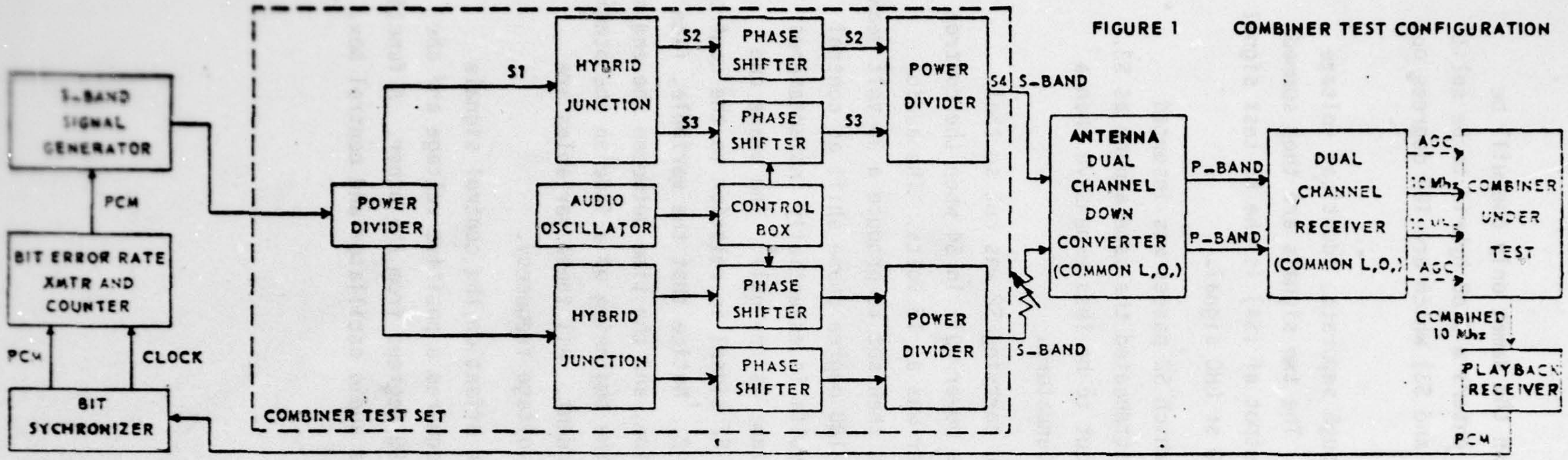
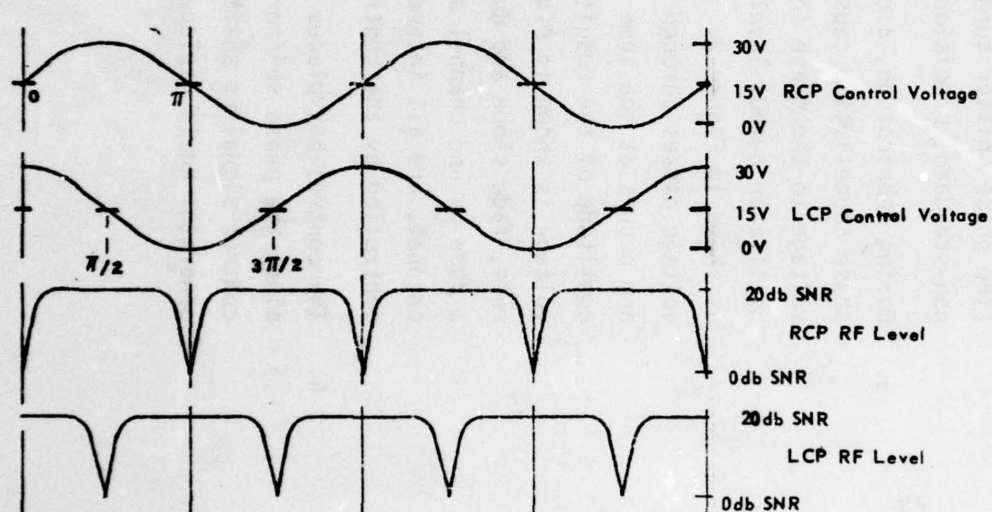


FIGURE 1 COMBINER TEST CONFIGURATION



COMBINER TEST SET CONTROL VOLTAGES.

FIGURE 2

2. Since both channels function the same, only one will be reviewed. The signal (S1) enters a 3 dB hybrid to be split into two equal signals (S2 and S3) which are 180 degrees out of phase.

3. Signals S2 and S3 pass through separate, identical voltage controlled phase shifters. The two signals are then summed in a power divider. The output of (S4) is the RF test signal representing either the RHC or LHC signal.

4. The phase shifter through which S2 passes was inserted only to ensure that S2 is attenuated the same amount as S3. (The phase shifter turned out to be less expensive than a non-standard, precision attenuator).

5. During fabrication, a cable carrying S2 was cut so that phase cancellation caused a power null in S4 when the control voltage to the phase shifter was at 15 volts. The audio oscillator output level was then set to produce a 30 volt peak as shown in Figure 2. The 180 degree phase shift as control voltage passes through 15 volts is essentially instantaneous and occurs at the same instant as the null. The phase and amplitude of the resultant RF signal in relation to the control voltage is shown in Figure 2. Notice that the variable, fade rate, fade slope and duration, and the time betweeen the end of a fade on one channel and the beginning of a fade on the other channel, are all interdependent. All these variables are controlled by the control voltage frequency.

6. The control box places a dc offset on the control signals since the phase shifters requires a positive voltage and one control signal is shifted 90 degrees from the other. A function generator could replace the audio oscillator and control box.

1.7.2 Test Procedure - Combiner BER Tests

The purpose of these tests is to measure the bit error rate versus signal-to-noise ratio (SNR) to determine SNR improvement of the telemetry diversity combiner under quasi-steady state conditions. Dynamic fading is then simulated by a test set to measure the combiner signal quality weighting circuitry speed for polarization diversity combining.

Equipment Used

S-band Signal Generator

BER Test Set, Model 7090

Spectrum Analyzer, H/P 141T

Power Meter, H/P 432A

PCM Bit Synchronizer

Combiner Test Set, FEC SCT-1

Equipment Configuration - Connect the equipment as shown in Figure 3.

Method

1. Connect the spectrum analyzer to the receiver 10 MHz IF output.
2. Set the signal generator output for a normal signal level (above -70 dBm) and adjust the deviation until the desired spectrum is obtained. Refer to procedure subsection 1.3 (para. 1.3.2), Signal Generator Calibration to determine the carrier and sideband levels for a given code type, bit rate, and type of modulation (FM or PM). Remove the spectrum analyzer.
3. Record the bit rate, code type, and deviation on the data sheet. Refer to sample on page 9.
4. Measure the noise power level, N, in unlimited IF output.
5. Disable AGC. Substitute bias which provides linearity over range N to 4 N.

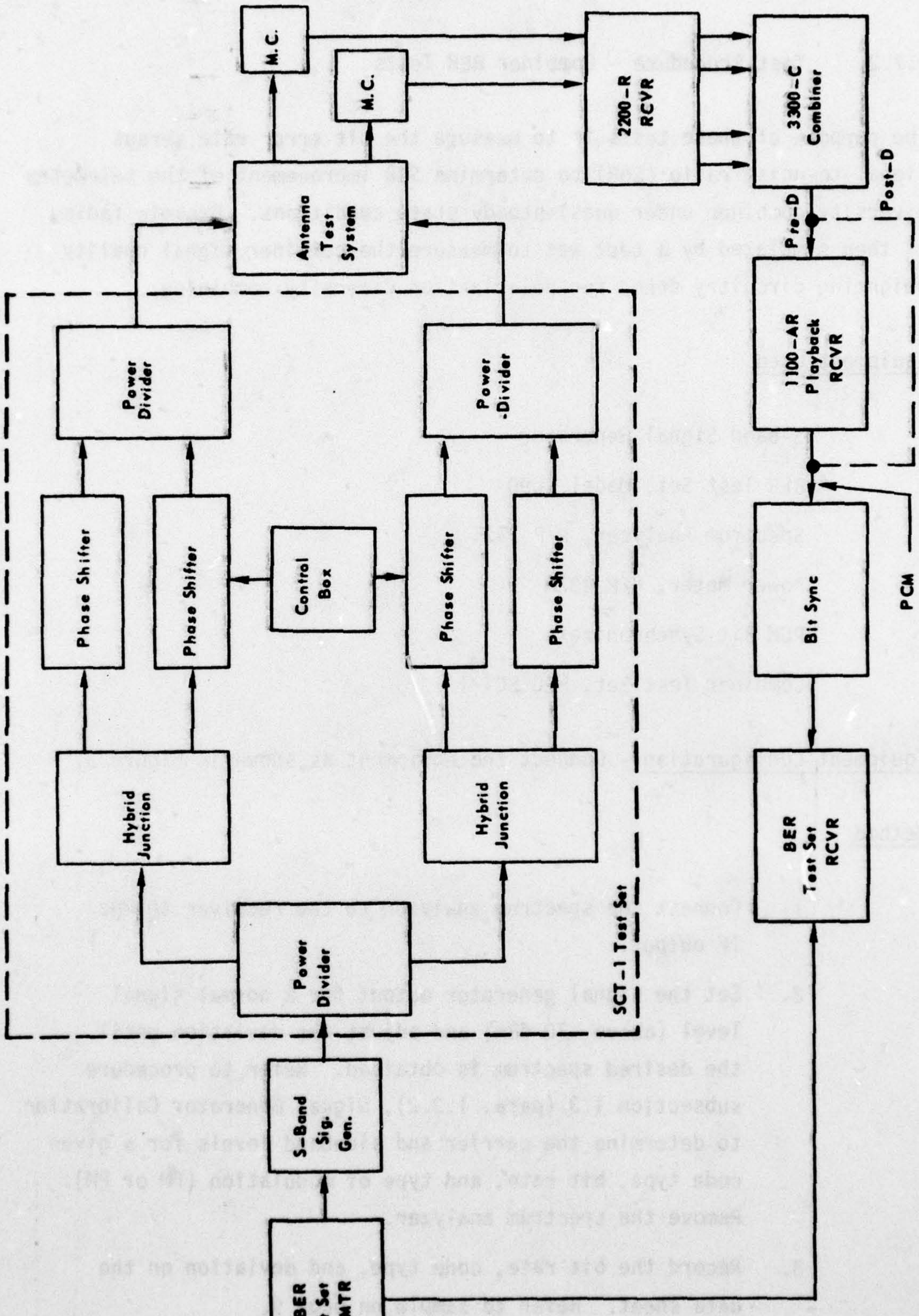


FIGURE 3 COMBINER BER TEST CONFIGURATION

With Ps of -130 dbm or less, measure output power or rms voltage (true). Ps = signal generator output power. Increase Ps until output meter reading increases 3 dB. Call this P_{si}. Then P_{si} = N.

6. To test linearity, check results against following table:

Ps	Output Power	dB increase (relative to N)
0 (or -130 dBm)	N	-
P_{si}	2N	3 dB
$2P_{si}$	3N	4.77 dB
$3P_{si}$	4N	6 dB

7. Record the signal generator attenuator setting at Ps = P_{si}. It now represents 0 dBb SNR.

8. Repeat steps 4 through 6 for the other receiver channel. 0 dB SNR of the two channels should be within 1.5 dB of each other on the signal generator attenuator dial. If the difference is greater, corrective maintenance is indicated.

9. Return the receivers to the normal AGC mode.

10. Set the signal generator output to +14 dB SNR in the receiver IF. If SGLS combiner tests are being conducted, set the +14 dB SNR in the baseband demodulator subcarrier bandpass filter. Set the SCT-1 test set fade rate to zero.

11. Decrease the signal generator output in 1 dB steps and record errors for each receiver channel and the combiner output until five levels of errors have been recorded.

12. Set the signal generator attenuator to obtain 10^5 data (one error per hundred thousand bits) on the single channel data and set the SCT-1 fade rate to 1.0 Hz. 10^5 combiner quality should be maintained when fading occurs.

13. Slowly increase the fade rate until the bit error rate increases to 10^4 data quality (10 errors per hundred thousand bits). The fade rate where the data quality degrades to 10^4 data quality is defined as the break point on the data sheet.

14. Repeat steps 12 and 13 at 20 dB SNR and record the break point on the data sheet. Since error free data is obtained at 20 dB SNR, the break point is defined as 10 errors per million bits.

Date______________________

Combiner Model No. 3300-C (A)

Combiner Ser. No. 068

Rcvr AGC Mode 0.1 ms

Bit Rate 345.6 kbs

PCM Code Type Bi-Ø-1

Subcarrier Deviation N/A

Carrier Deviation ± 1.4 radians

Pre-D______________ Post-D______________

Steady State Checks

IF SNR	Ch 1	Ch 2	Combined
	Errors per million bits		
14	0,0,0	0,0,0	0,0,0
13	0,0,0	0,0,0	0,0,0
12	0,0,0	0,0,0	0,0,0
11	0,0,0	0,0,0	0,0,0
10	0,0,0	0,2,2	0,0,0
9	4,1,1	14,17,17	0,0,0
8	13,9,8	68,54,65	0,0,1
7	89,83,69	236,232,276	1,1,4
6	336,356,318	949,1044,1014	9,16,1
5	2550,1970,3740	-, -, -	76,54,74
4	-, -, -	-, -, -	290,334,298

Dynamic Checks:

	Break Point
10^5 data quality check	390
20 dB SNR data	520

Sample Data Sheet Combiner Test

FIGURE 4

NOTCH NOISE POWER RATIO TEST

In this test, a white noise signal of specified bandwidth is transmitted to simulate a full complex FM/FM baseband loading format for reference. Notch or band-stop filters block out the noise over a narrow bandwidth at the frequencies to be tested. If the depth of the notch is less after passing through the system under test (e.g. an antenna preamp, a receiver and a combiner), then the system has caused degradation by intermodulation distortion or by high system thermal noise levels. Each of these conditions can be easily identified.

The notch noise test has been applied to a wide variety of systems such as microwave and tape recorders. A few of the many references are:

1. TP-75-21, Relationship of NPR to Subcarrier Discriminator Output Signal-to-Noise Ratio, Pacific Missile Test Center, Point Mugu, California, August 1975.

2. Report P100-72-33, Test Procedure for Microwave Evaluation, Vandenberg AFB, California: FEC Systems Performance Analysis Directorate, 1972.

3. Technical Memorandum: Effect of Second Harmonic Distortion on Baseband Recording, from M. H. Nichols to the Performance Analysis Department of Federal Electric Corp., Vandenberg AFB, California, January 1975.

1.8.1 Theory

Noise Power Ratio (NPR) testing is an accepted procedure for detecting and evaluating the levels of noise and intermodulation distortion in multi-channel frequency division multiplex telemetry systems. This is done by inserting a white noise signal of known levels with a uniform continuous frequency spectrum into the system, which simulates actual operational conditions. The white noise has statistical properties similar to those of a subcarrier multiplex signal and can provide a fairly accurate method of simulating the multiplexed load in wideband transmission systems. The noise loading method of testing presently is the only practical means of determining the full dynamic load capacity of multichannel telemetry systems.

The technique for performing white noise loading measurements is shown in Figures 1 and 2. The system under test is loaded with band limited white noise from the noise generator to simulate full loading conditions. A noise receiver (or calibrated spectrum analyzer) at the system output is adjusted for an appropriate output level reading and the noise level is recorded as P_1.

A quiet channel (or notch) is then produced by activating a bandstop filter in the noise generator. A band pass filter corresponding to the quiet channel is selected in the receiver and the noise power in the notch is recorded as P_2. Since the quiet channel, as produced by the noise receiver, contains very little noise power, the noise power recorded may be considered to consist of intermodulation distortion (N_i) and thermal noise (N_o) present in the system under test. The NPR of the system is then:

$$NPR = \frac{P_1}{P_2} = \frac{S + N_o + N_i}{N_o + N_i}$$

If the input noise spectrum is altogether removed and the output power measured, the power difference with respect to the reference value, P_1, is called the thermal power ratio (TPR or NPRF in IRIG 118-73), and is a measure of the additive noise alone.

At low signal-to-noise ratios where nonlinear distortion effects are overshadowed by system noise, the NPR is the same as the TPR. The nonlinear effects begin to become more pronounced as the signal-to-noise ratio is increased and NPR becomes less than NPRF, because the latter is always measured with the modulation removed. The NPRF performance is the limit which NPR performance cannot exceed.

A second value, NPRI, which is a measure of intermodulation distortion alone, may be calculated by the addition of a parameter, Δ (dB), to the NPR where:

$$NPRI = NPR + \Delta$$

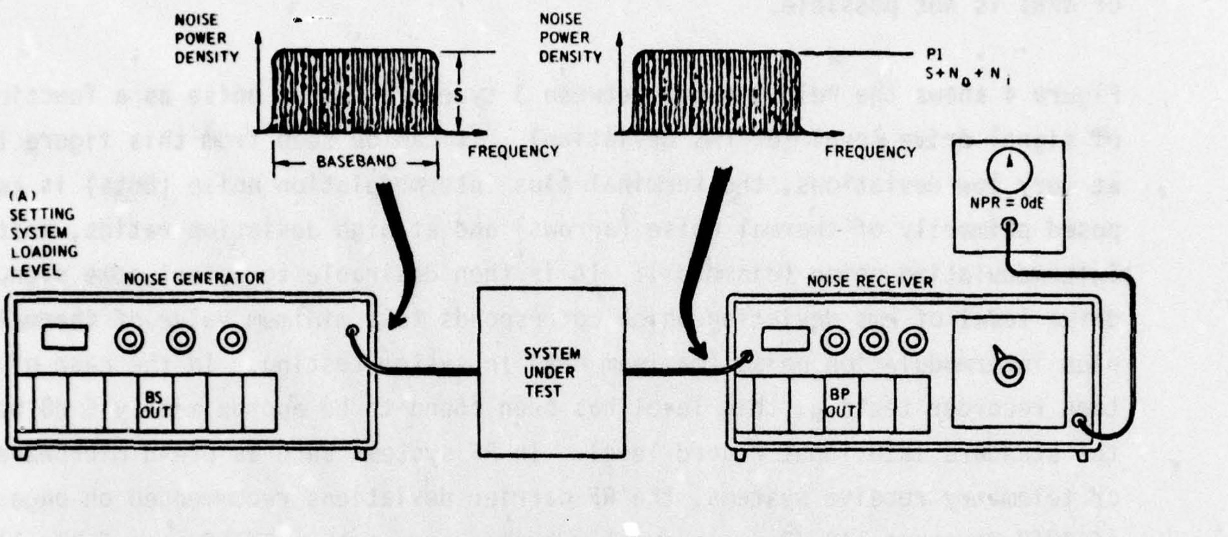


FIGURE 1 NPR PRE-CALIBRATION OF TEST SET-UP

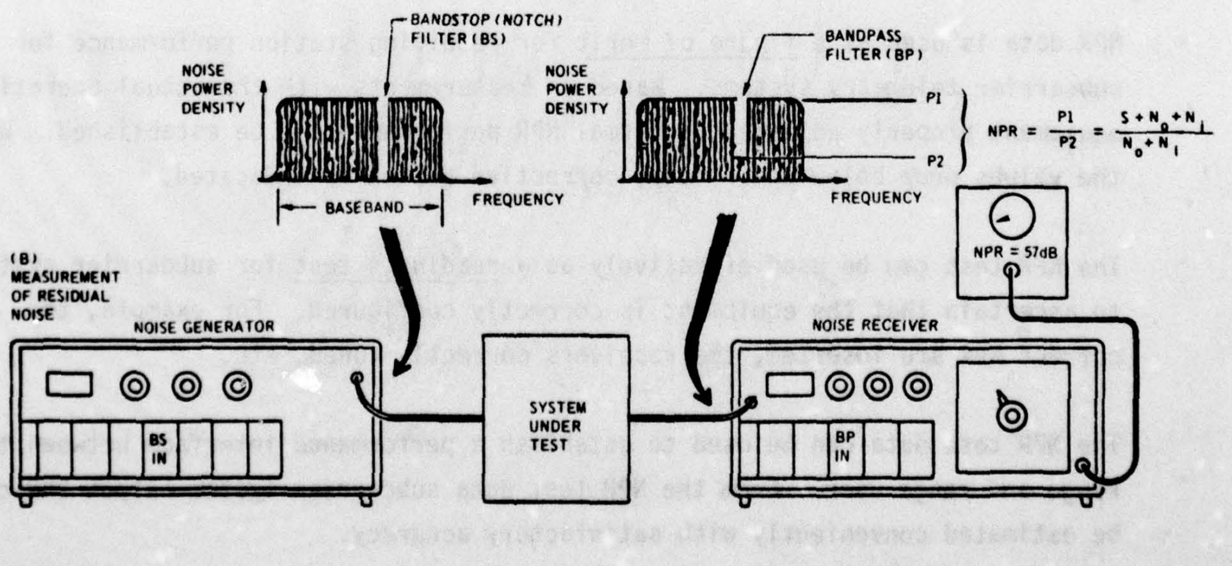


FIGURE 2 NPR TEST SET-UP WITH SLOT FILTER ACTIVATED

The parameter Δ (dB) is taken from the curve of Figure 3. The difference (in dB) between NPR and NPRF is determined and the corresponding Δ, (amount to be added to NPR to give NPRI) is read directly from the graph. At the lower signal-to-noise ratio(SNR) levels, the NPR readings may become masked by the NPRF readings, as previously explained. In such cases, the calculation of NPRI is not possible.

Figure 4 shows the relationship between 3 types of system noise as a function of signal drive level (or rms deviation). It can be seen from this figure that at very low deviations, the terminal plus intermodulation noise (Dots) is composed primarily of thermal noise (arrows) and at high deviation ratios, mostly intermodulation noise (diamonds). It is then desirable to select some signal drive level of rms deviation which corresponds to a minimum value of thermal plus intermodulation noise (maximum NPR) in system testing. In the case of tape recorder testing, this level has been found to be approximately 6 dB below the standard IRIG input record level. In RF systems such as pre-d microwave or telemetry receive systems, the RF carrier deviations recommended on page 68 of IRIG Document 118-73 are currently being used at the SAMTEC (see Table 1) until the best deviation for each format supported by the range can be determined.

NPR data may be used as a figure of merit, as a readiness test and as a range user interface.

NPR data is used as a <u>figure of merit</u> for receiving station performance for subcarrier telemetry systems. Based on measurements with the actual operating equipment properly adjusted, a normal NPR performance can be established. When the values drop below their norm, corrective action is indicated.

The NPR test can be used effectively as a <u>readiness test</u> for subcarrier systems to ascertain that the equipment is correctly configured. For example, the correct NPR are inserted, the receivers correctly tuned, etc.

The NPR test data can be used to establish a performance interface between the range and range user. From the NPR test data subcarrier system output SNR can be estimated conveniently with satisfactory accuracy.

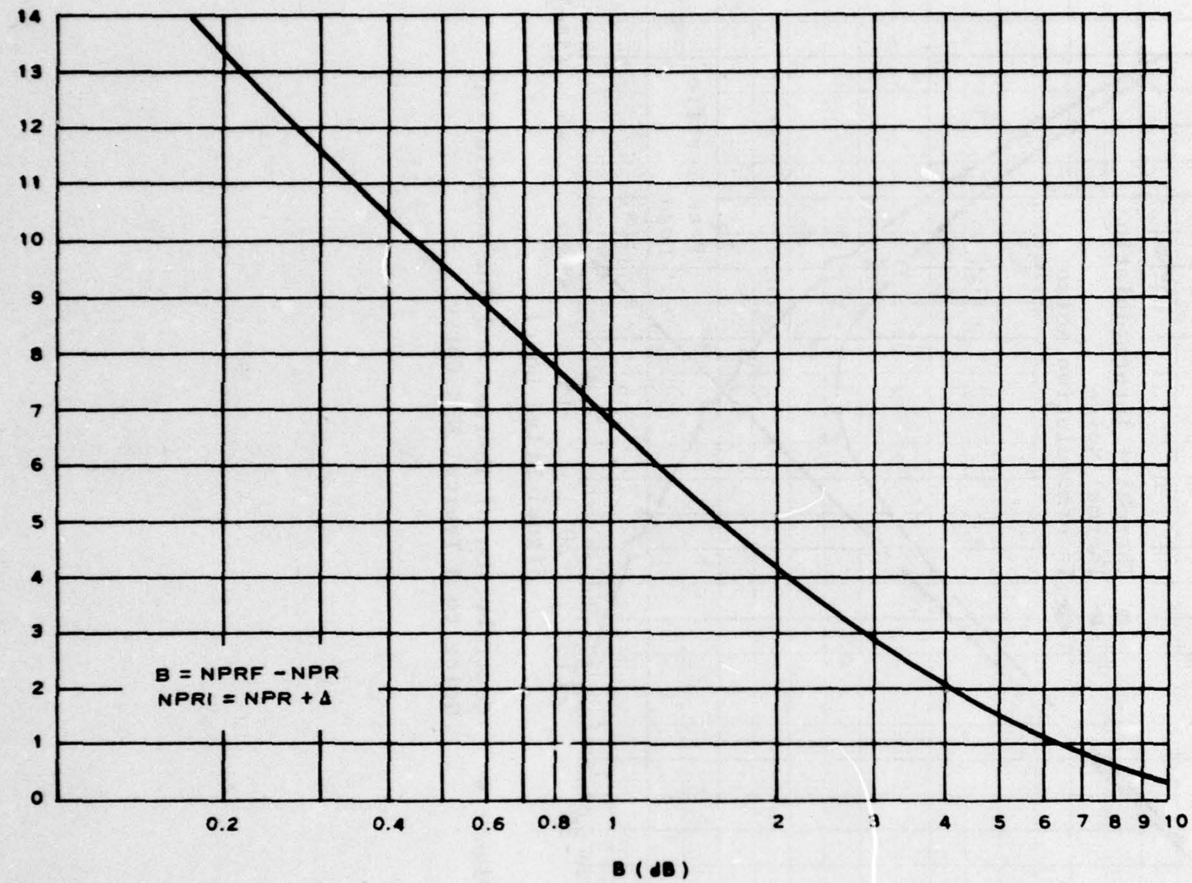


Figure 3 Curve for Converting NPR and NPRF Data to NPRI

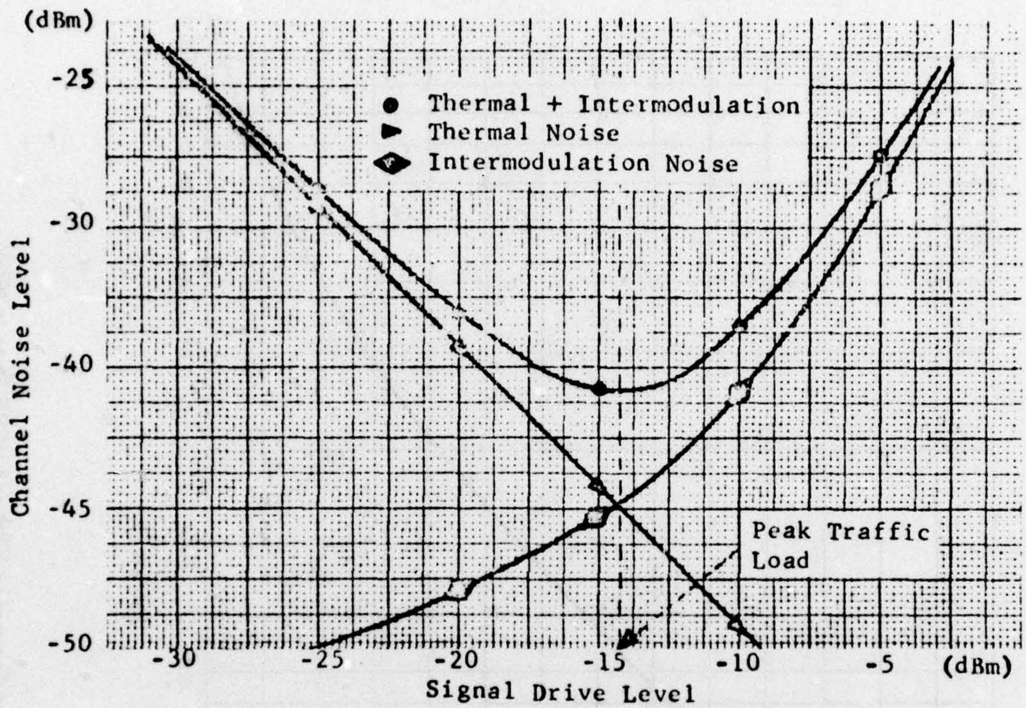


Figure 4 Contribution of Thermal and Intermodulation Noise to a Typical NPR Curve

The following was reproduced from IRIG Document 118-73, page 68.

IF Bandwidth (KHz)	Modulation Freq. NPR Baseband (kHz)	Video Bandwidth (DC to kHz)	Deviation (kHz rms)
300	12 - 108	150 - 200	25
500	12 - 108	150 - 200	55
	12 - 156	175 - 300	50
	12 - 204	225 - 400	40
750	12 - 108	150 - 200	95
	12 - 156	175 - 300	85
	12 - 204	225 - 400	80
1000	12 - 204	225 - 400	125
1500	12 - 204	225 - 400	210
3300	12 - 204	225 - 400	530

RF Input Power = Variable (see data sheet)
Demodulator Bandwidth = Wide (1.5 MHz)

Table 1 NPR Test Conditions

AD-A050 503 FEDERAL ELECTRIC CORP VANDENBERG AFB CALIF F/G 9/6

TELEMETRY SYSTEMS CALIBRATION AND VALIDATION HANDBOOK.(U)

SEP 77 R G STREICH, G JOHNSON F04703-77-C-0111

UNCLASSIFIED PA100-77-40 SAMTEC-TR-78-56 NL

2 OF 3

AD A050503

The following two examples are for estimating the output signal-to-noise ratio by use of NPR with flat test taper. The first is for CTSW with a 6 dB/octave taper with a breakpoint at 23 kHz as in Reference 1. For the flat taper NPR given in Reference 1, Table 9 is used. The second example is for PBW using the 9 dB/octave taper with a breakpoint at 23 kHz. NPR data characteristics of predetection recording are used.

Example 1 - The estimation is for the 72 kHz CBW channel for the multiplex defined on page 5 Reference 1. The 500 kHz IF bandwidth data are used. The NPR data of Table 9 are also used. Note from Table 9 that the NPR and NPRF (Reference 1 has the definition) are nearly equal for all but the 40 dB carrier SNR. This is to say that for all other cases the thermal noise swamps out the intermodulation noise.

In the example, assume carrier SNR of 21 dB and 12 dB. Since the thermal noise swamps out the intermodulation noise, NPRI >> NPRF so that NPR ≃ NPRF. In this case, equation (10) of Reference 1 is used. Equation (11) is used to make use of the NPR data with the flat test spectrum. From Tables 43 and 44, Reference 1 $f_{c'} = 72$ kHz.

$$\frac{S_{xxt}(f_i)}{S_{xxf}(f_i)} = \frac{0.1152}{0.1000} \simeq 1.15$$

So $NPRF_t'(72) \simeq 1.15\ NPRF_f'(72)$

Note from Table 9 of Reference 1 that NPRF' is essentially equal to NPRF. Substitution into Reference 1 equation (10) and using the numbers in Table 1 for D = 2, gives the value in Table II.

Table II
Carrier SNR vs. NPRF

Carrier SNR dB	Measured Output SNR dB from Table 13, Ref 1	Estimated Output SNR dB	NPRF dB from Table 9, Ref 1
21	40	41.6	27
12	30	31.6	17

From equation 10, Reference 1

$$\left(\frac{S}{N}\right)_{di} = 3 \times 4.24 \times 2 \times 1.15 \text{ NPRF}'\ (72)$$

or in dB

$$\left(\frac{S}{N}\right)_{di} = 14.6 + \text{NPRF}_f'(72) \text{ dB.}$$

To compute Table 1, it was assumed that $\text{NPRF}_f'(70) \simeq \text{NPRF}_f'(72)$. As can be seen from Table 9 of Reference 1, this is a good approximation.

Example 2 - The estimated output SNR of 93 kHz subcarrier with a deviation ratio of 1.3 in the PBW multiplex are defined on page 6 of Reference 1. The data in this reference are characteristic of good equipment, well adjusted, and do not include predetection tape recording. To illustrate a case involving more intermodulation, consider the case of predetection recording of an FM carrier where the NPR/NPRF for the 105 kHz notch are 34/41 dB (see, for example, Hedeman and Nichols, ITC Proceedings 1972, page 59). These data are for large carrier SNR. A rough plot of these data is shown in Figure 5. From the the NPR/NPRF for 93 kHz are approximately 36/42.

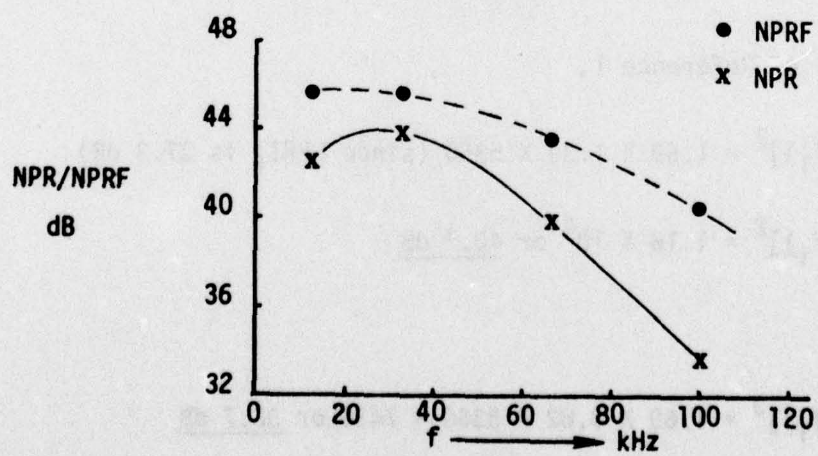


Figure 5

NPR/NPRF VS FREQUENCY

From Figure 31, page 70 of IRIG Document #118-73, NPRI can be found in terms of B = NPRF - NPR = 42 - 36 = 6 dB. For this Δ = 1.3 dB, so NPRI = 36 + 1.3 = 37.3 dB.

Note that NPRF $\approx$ NPRF' and NPRI $\approx$ NPRI'.

In order to substitute into equation (9) of Reference 1 and making use of Table 2 of the same reference, we must have the tapered NPRF' and NPRI' in terms of the flat taper data as follows.

From Tables 43 and 45 for f_i = 93 kHz

$$\frac{S_{xxt}(f_i)}{S_{xxf}(f_i)} = \frac{0.1689}{0.1000} \simeq 1.69$$

$$\frac{S^{(2)}_{xxf}(f_i)}{S^{(2)}_{xxt}(f_i)} = \frac{0.7400}{.5713} \simeq 1.30$$

$$\frac{S^{(3)}_{xxt}(f_i)}{S^{(3)}_{xxt}(f_i)} = \frac{19.11}{23.29} \simeq 0.82$$

From equation (11) of Reference 1,

$$NPRF'_t(f_i) = 1.69 \text{ X } 1.57 \text{ X } 10^4 \text{ (since NPRF' is 42 dB)}$$
$$= 2.67 \text{ X } 10^4 \text{ or } \underline{44.2 \text{ dB}}.$$

From equation (12) of Reference 1,

$$[NPRI'_t(f_i)]^2 = 1.69 \text{ X } 1.30 \text{ X } 5360 \text{ (since } NPRI'_f \text{ is 37.3 dB)}$$

$$[NPRI'_t(f_i)]^2 = 1.18 \text{ X } 10^4 \text{ or } \underline{40.7 \text{ dB}}$$

and

$$[NPRI'_t(f_i)]^3 = 1.69 \text{ X } 0.82 \text{ X } 5360 = 7430 \text{ or } \underline{38.7 \text{ dB}}$$

With the values from Tables 1 and 2 of Reference 1, substitute into equation (9) of the same reference. In Table 1, ΓD^3 for 70 kHz with D = 1.31 is used.

$$\left[\left(\frac{S}{N}\right)_{di}\right]^2 = \frac{3 \times 1.73 \times 2 \times 2.67 \times 10^4 \times 1.18 \times 10^4}{1.2 \times 2.67 \times 10^4 + 1.18 \times 10^4} = 7.5 \times 10^4 \text{ or } \underline{48.7 \text{ dB}}$$

$$\left[\left(\frac{S}{N}\right)_{di}\right]^3 = \frac{3 \times 1.73 \times 2 \times 2.67 \times 10^4 \times 7.43 \times 10^3}{1.3 \times 2.67 \times 10^4 + 7.43 \times 10^3} = 4.9 \times 10^4 \text{ or } \underline{46.9 \text{ dB}}$$

The smaller value, 46.9, is the conservative estimate.

1.8.2 Test Procedure

The purpose of this test is to measure the intermodulation products and residual noise in FM receive/record systems. The following equipment is used:

- notch noise generator
- notch noise receiver*
- high pass filter - 12 kHz
- low pass filter - 108 kHz, 152 kHz, 156 kHz, 204 kHz
- bandstop (transmit and receive) 14, 34, 70, 152 kHz
- signal generator (RF testing only)
- spectrum analyzer (*may be substituted for notch noise receiver)
- true rms voltmeter (HP 3400A)
- test oscillator (HP 200CD)

Refer to procedure in subsection 1.3 of this handbook for the signal generator calibration procedures.

Refer to procedure 4.2 in section 4.0 for simulation configuration of specific launch vehicle data formats.

Refer to Table I for rms deviation consistent with the noise and receiver IF bandwidths.

1. Calibrate the signal generator deviation to the required rms deviation as shown in Table I corresponding to the noise bandwidth and receiver IF.

2. At the noise generator, switch in the reqired high and low pass filters to be used during the test. Switch out all other filters.

3. Adjust the output attenuators and noise level control for a noise generator output level to produce the desired deviation found during the calibration of the signal generator.

4. Set up the equipment as shown in Figure 6 and adjust the receiver 2nd IF SNR to 9 dB. At the noise receiver, adjust the set reference control to give a meter reading on the REF MARK, then adjust the spring loaded course and fine attenuator skirts to the 0.0 position.

5. Switch in the first notch filter (14 kHz) at the noise generator and the first band stop filter (14 kHz) at the noise receiver. The meter reading on the noise receiver will drop because of the loss of power in the notch.

6. Adjust the course and fine input attenuators so that the noise receiver meter indication is restored to the reference mark. The noise power ratio (NPR) is obtained by adding the coarse and fine input attenuator readings. Enter this figure on the test data sheet (Fig. 7) under the NPR heading.

7. At the noise generator, insert maximum attenuation into the generator output. At the noise receiver, again read the power in the first notch (14 kHz). Record this number under the heading NPRF. From Figure 3, determine the Δ to be added to NPR to give NPRI. Record the NPRI on the data sheet.

8. Reset the noise generator output attenuator to the previous calibration level. Switch the first notch out and the second notch in. Repeat the above procedure for all required notch frequencies.

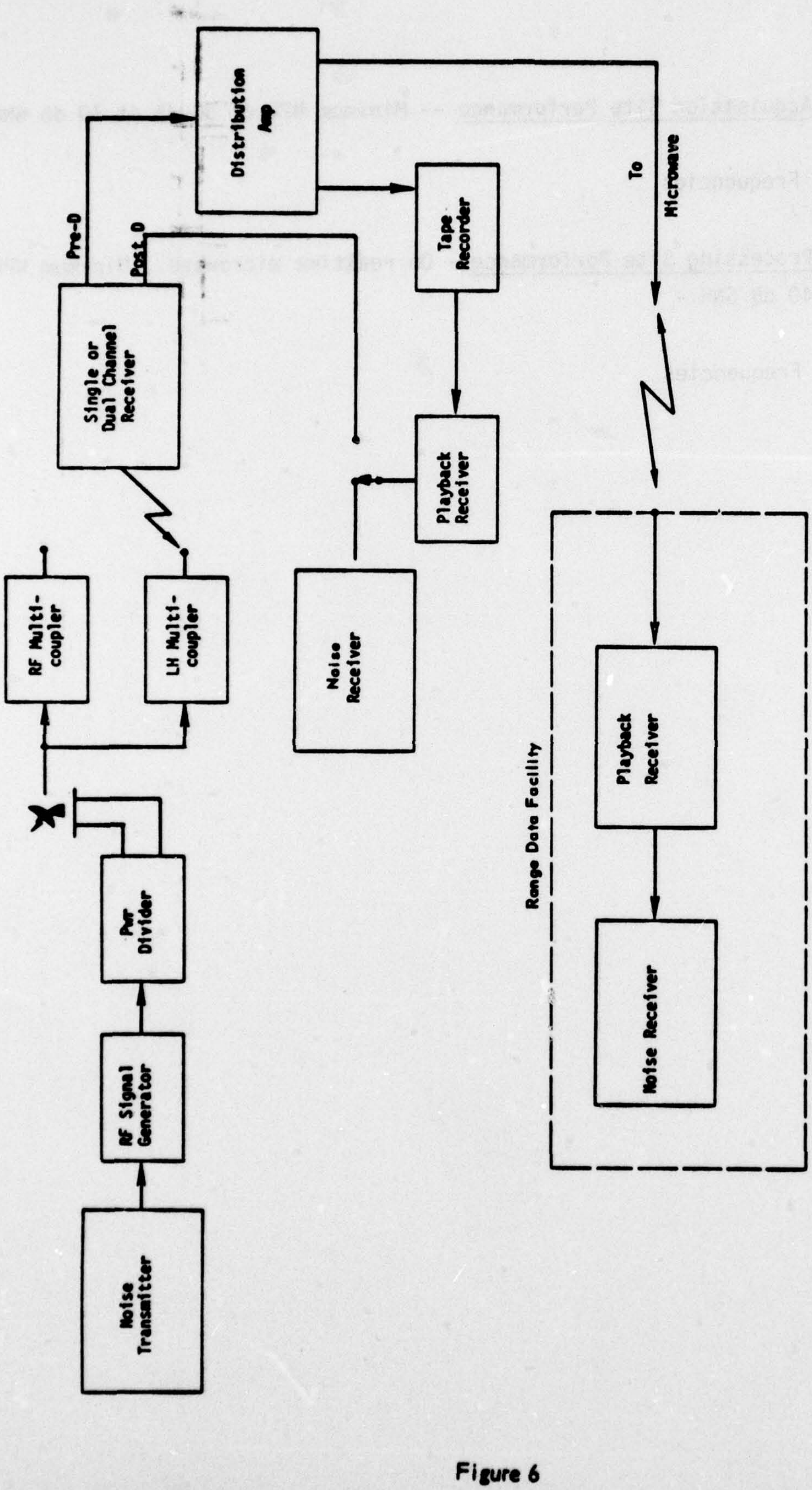
9. Repeat the test procedure at 15 dB SNR and at 40 dB SNR.

Required Acquisition Site Performance -- Minimum NPR of 30 dB at 40 dB SNR -

All Notch Frequencies

Required Processing Site Performance - On realtime microwave...Minimum NPR of 27 dB at 40 dB SNR -

All Notch Frequencies



NOTCH NOISE TEST CONFIGURATION NO. 6

Figure 6

Noise Power Ratio Test

Link ______________________________ RCVR ________________ Serial No. ______________

Test Personnel: ____ Date: _________________

IF Signal-to-Noise Ratio = 40 (or max ___ dB)											
IF Band-width (kHz)	Mod Freq. Band (kHz)	Devia-tion (kHz rms)	V_1 (volts rms)	NPR/ NPRF (dB) Notch Freq. (kHz)				NPRI (dB) Notch Freq. (kHz)			
				14	34	70	105	14	34	70	105
300	12-108	25	0.125								
500	12-108	55	0.275								
750	12-108	95	0.475								
				14	34	70	152	14	34	70	152
500	12-156	50	0.250								
750	12-156	85	0.425								
				14	34	105	185	14	34	105	185
500	12-204	40	0.200								
750	12-204	80	0.400								
1000	12-204	125	0.125								
1500	12-204	210	0.210								
3300	12-204	530	0.530								

Figure 7 Test Data Sheet

1.9 ANTENNA RADIATION PATTERN MEASUREMENT

1.9.1 Theory

Primary antenna radiation patterns are normally recorded at the manufacturer's facility on the RF feed assembly. These patterns are made with the feed mounted on a calibrated reflector such as an eight foot diameter parabola in an anechoic chamber or in an antenna range of known accuracy. The secondary pattern measurement described in this section is made with the feed mounted in its operating environment. At the SAMTEC these secondary patterns are periodically recorded for the 30 foot, 35 foot, 40 foot and 80 foot autotrack antennas.

The performance specifications to be verified from the patterns are 3 dB beamwidth of the sum channel, sidelobe suppression on the sum channel shape and symmetry of both the sum and difference channels, difference channel depth of null, coincidence of the sum channel peak and difference channel null and consistency across the frequency band. The patterns are used in conjunction with solar calibrations, radiometer measurements and antenna pointing capability tests in other sections of this handbook. Patterns often display unusual characteristics in the operational environment due to multipath. In fact, as many as ten percent of the patterns taken on one day may appear unacceptable. But in repeating the same measurement a few hours later will show acceptable results while a pattern at a previously acceptable frequency will appear unacceptable. If 90 percent of the patterns show acceptable performance, then testing progresses to corroborative tests such as solar calibrations or the tracking tests of antenna pointing capability. Due to the equipment, manpower, and scheduling requirements, patterns are recorded only when an antenna feed is modified (such as the addition of L-band capability on an S-band system) or repaired.

Figure 1 shows a typical pattern of the 35 foot antenna which has a parabolic reflector with a pseudo-monopulse feed at the focal point. The 3 dB beamwidth specification is 0.8 degrees minimum with 20 dB minimum sidelobe suppression. The minimum beamwidth is specified to ensure that the gain specification is not met at the expense of the beamwidth needed for acquisition and tracking. Note the symmetry about the center of the main beam. The difference channel null

falls correctly at the peak of the main beam. Figure 2 shows the effects of multipath. The first sidelobe appears too far away from the center of the main beam while the main beam itself is distorted. Actually, the multipath has caused the null between the main beam and first sidelobe to disappear. The only method of rapid resolution of the apparent problem is to use a high elevation boresight source such as a satellite. The sun is not suitable because it is not a point source and does not have sufficient energy to measure sidelobe levels at 20 dB below the peak gain.

If poor patterns are observed at numerous frequencies, solar calibrations are made to confirm the gain of the antenna. Then tracking error voltage gradients are plotted to verify beam shape. The error voltage level versus the angular offset from a boresight signal in azimuth and elevation (one axis at a time) will quickly show any problems.

1.9.2 Requirements

Test Conditions - The test shall be performed under on-site ambient conditions of pressure, temperature and humidity provided that the temperature is within the range of 40 to 100 degrees F. Testing shall not be conducted when rainfall rates are greater than 1 inch per hour or when dense fog restricts visibility to less than 100 feet.

Test Records - Records of each antenna pattern measurement when completed and documented as noted herein shall be forwarded to the Performance Analysis Department. Test interruptions and test failures shall be noted on the test procedure and described briefly on the page of the test procedure provided for this purpose.

Failure Reporting - In the event the antenna equipment fails during the test, an equipment failure report shall be initiated in accordance with the policy of the Maintenance Data Collection System. Complete information regarding the identification of equipment, i.e. work unit codes, shall be included in the report. The reports shall be forwarded to the Performance Analysis Department.

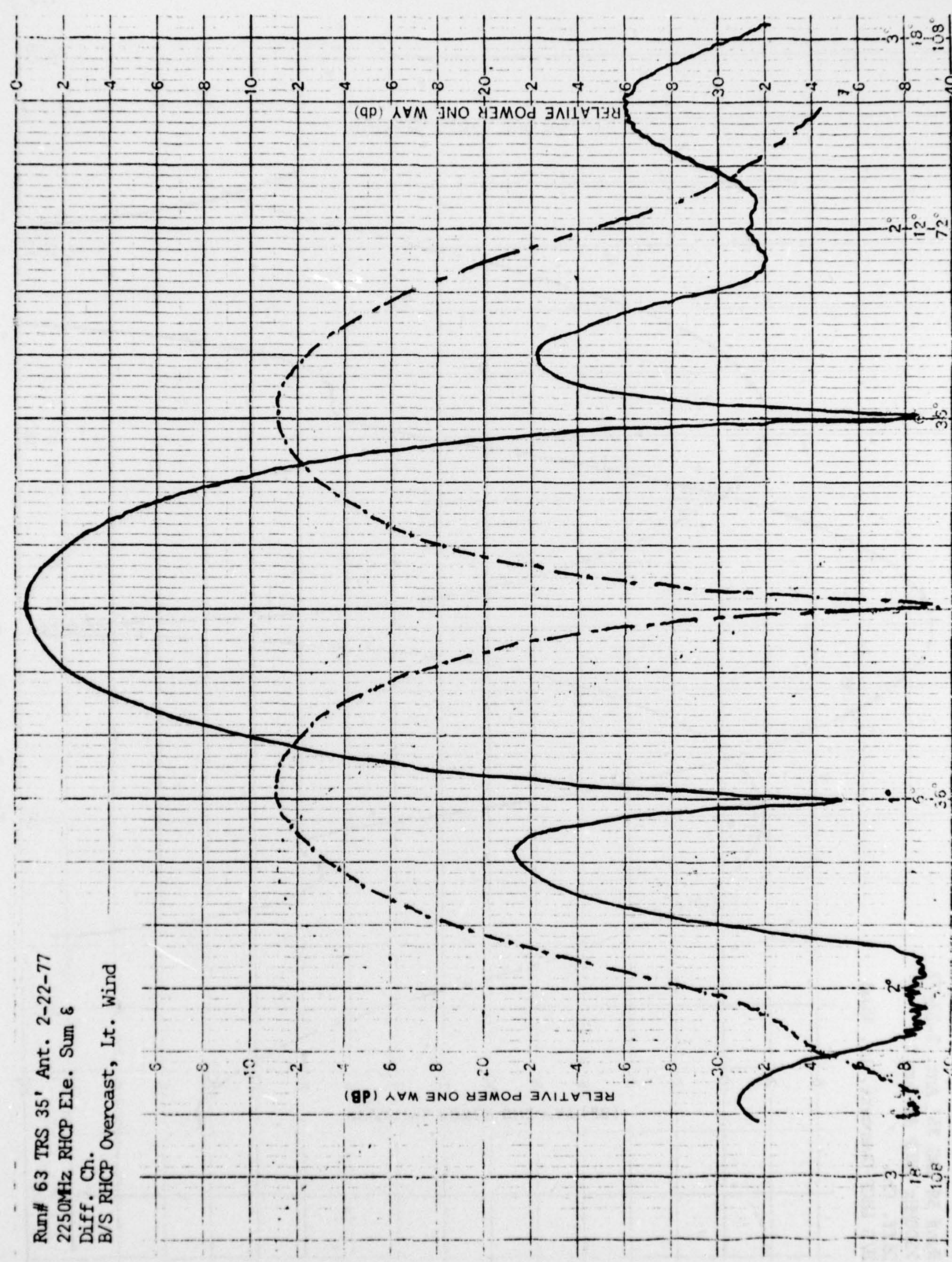


Figure 1
Antenna Pattern No. 1

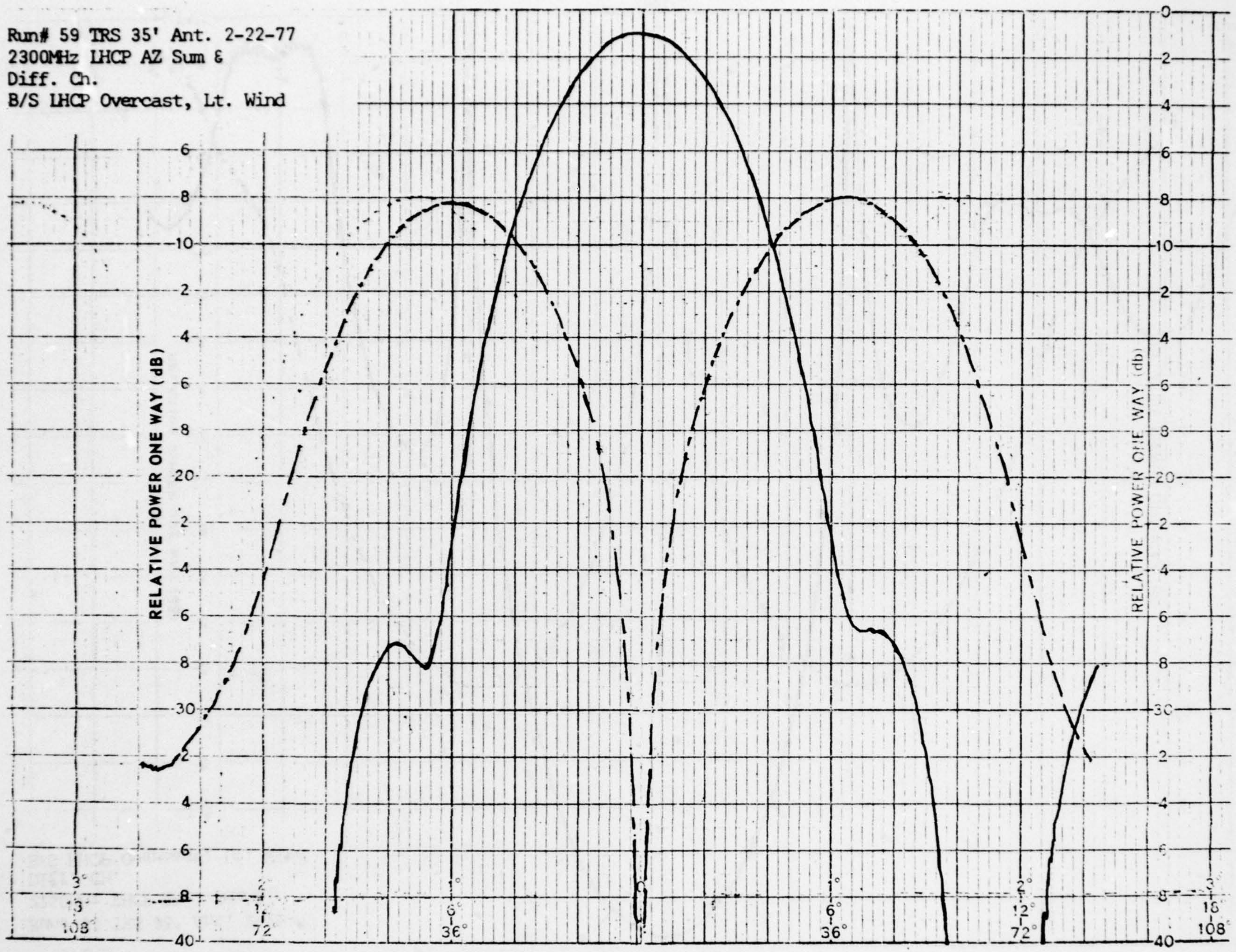


Figure 2 Antenna Pattern No. 2

Measurements - All performance measurements shall be made with instruments whose accuracy has been certified by PMEL.

Tolerances - The tolerance of all calibration measurements, including instrumentation error, shall be plus or minus ten (10) percent unless otherwise specified.

Test Equipment - The test equipment listed in Table I, or equivalent test equipment, shall be used for performing antenna radiation pattern measurements at each P, L or S-band frequency.

1.9.3 Test Procedure

The following paragraphs describe the procedure to measure antenna radiation patterns.

Initial Measurements

1. Position boresight antenna RF signal source at a distance R from the test antenna where

   $$R \geq \frac{2D^2}{\lambda}$$ (e.g., $R \geq 1500$ meters for a 10 meter parabola at 2250 MHz.)

   where R = Diameter of antenna under test

   λ = Test Wavelength

2. Mechanically align the axims of the boresight source to the RF axis of the antenna under test. Set azimuth and elevation indicators of the pattern recorder to 0°. Use difference channel depth of null to set azimuth and elevation RF axis to 0°. Position boresight at maximum received signal at the test antenna. Polarization angle, ϕ, is defined in Figure No. 3 .

3. Set up the test equipment as shown in Figure No. 4. A power amplifier (TWT) may be inserted at point A, if required. Turn on ac power and allow 1/2 hour warm up before measurement.

Table I

Equipment List

Item	Nomenclature	P-Band		L-Band		S-Band		Qty.
		Mfr.	Model	Mfr.	Model	Mfr.	Model	
1.	RF Signal Source	HP	608E	HP	8614	ACL	307-GI	1
2.	Directional Coupler	HP	744D	HP	7780	HP	797D	1
3.	Power Meter	HP	431C	HP	431C	HP	431C	1
4.	Portable Microwave Receiver	S.A.	1710	S.A.	1710	S.A.	1710	1
5.	15 ft. Type RG 223 COAX EQ/W Type N (Male) Connectors	S.A.	RG 223	S.A.	RG 223	S.A.	RG 223	1
6.	Broad Band Coax Mixer			S.A.	14-3(45)	S.A.	14-3(45)	1
7.	Low Frequency Converter 20-949 MHz	S.A.	1720					1
8.	Rectangular Pattern Recorder	S.A.	1520	S.A.	1520	S.A.	1520	1
9.	Crystal Bolometer Amplifier	S.A.	1554-2	S.A.	1554-2	S.A.	1554-2	1
10.	Frequency Counter EQ/W Plug-in	HP	5245L/ 5253A	HP	5245L/ 5254A	HP	5245L/ 5254	1
11.	Power Amplifier	HP	230B	HP	489A			1
12.	TWT Amplfier					HP	491A	1
13.	Log Spiral Antenna 200 MHz -1.0 GHz	Electro Mechanics	CLP-1A					1
14.	Log Spiral Antenna 1.0 GHz -10.0 GHz			Electro Mechanics	CLP-1B	Electro Mechanics	CLP-1B	1

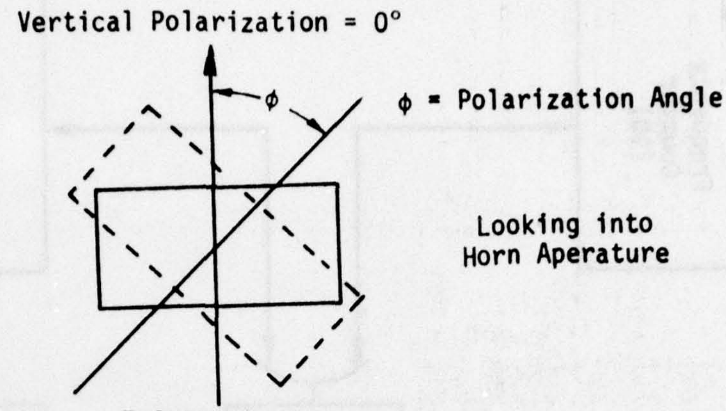


FIGURE NO. 3

BORESIGHT ANTENNA POLARIZATION DEFINITION

Antenna Radiation Pattern Measurement

1. Verify the signal generator frequency using the 5245L frequency counter and appropriate 5252A (P-band) or 5254A (L or S-band) plug-ins.

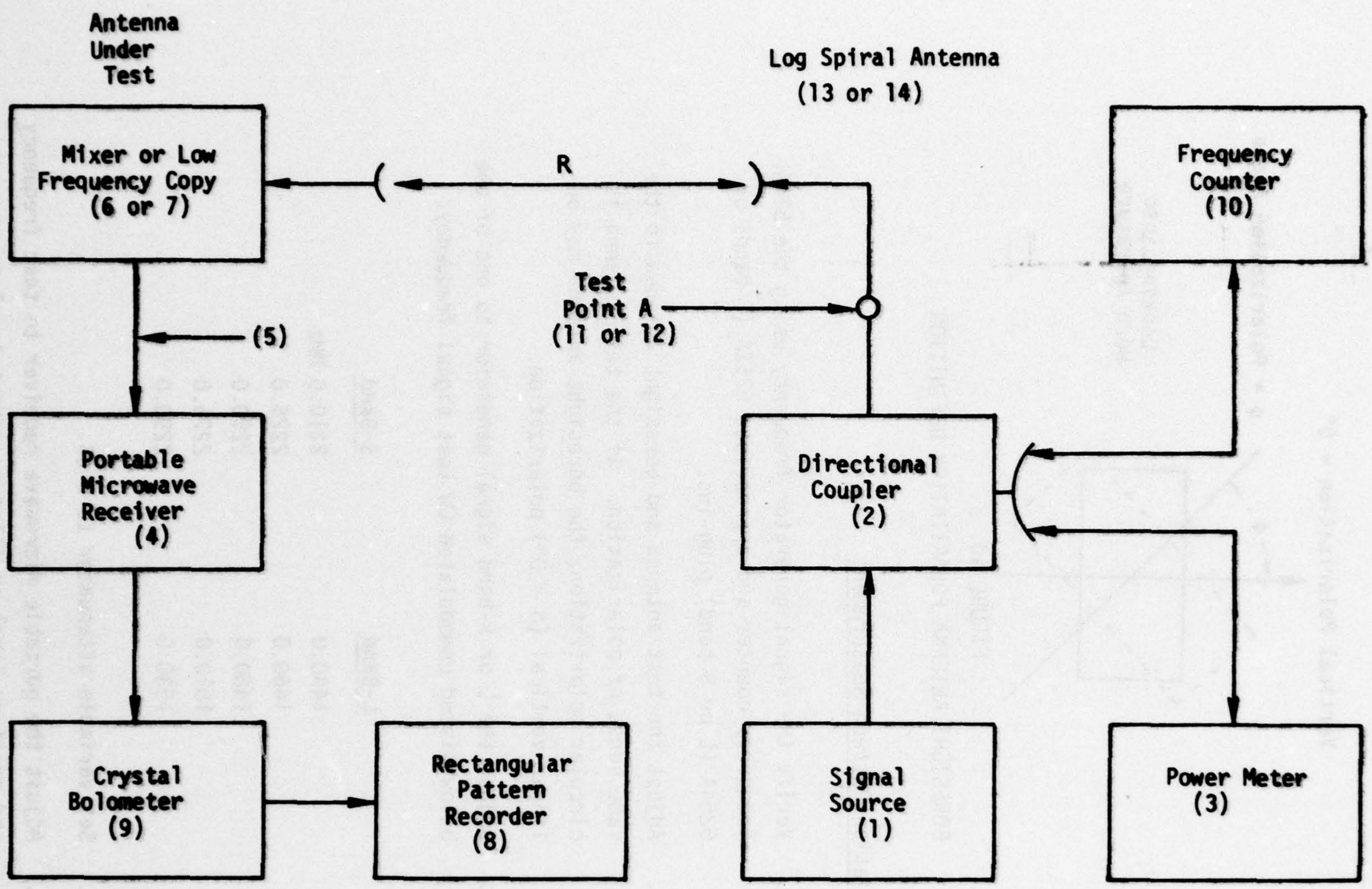
2. Adjust the test antenna and boresight antenna to the same sense of polarization. *If the test antenna is* circular polarization, the boresight antenna may be linear vertical ($\phi = 0°$) polarization.

3. Adjust the L or S-band signal generator to one of the below listed unmodulated CW test signal frequency:

L-Band	S-Band
1440.0	2210.0 MHz
1460.0	2225.0
1480.0	2250.0
1510.0	2275.0
1530.0	2290.0

4. Set variable attenuator to 0 dB.

5. Adjust the portable microwave receiver to test frequency and receiver local oscillator current level to approximately 2 milliampers with the 14-3 mixer. When using the Model 1720 receiver convertor set the "LO" pot to



BLOCK DIAGRAM TEST CONFIGURATION
ANTENNA RADIATION PATTERN MEASUREMENTS

Figure No. 4

mid range. Adjust receiver gain to approximately 3/4 full scale. Adjust the pattern recorder gain controls to position pen at -2 dB on pattern paper.

6. Adjust the receiver IF attenuator to 3 dB. Record pen position on pattern paper.

7. Repeat step 6 for variable attenuator settings of 10, 15, 20, 25 and 30 dB.

8. If pen response is compressed or nonlinear, adjust the receiver gain and/or signal generator level to obtain linear pen response and maximum dynamic range.

9. Record the final calibration points and dynamic range on pattern paper.

10. Azimuth pattern measurements shall be made with the elevation on boresight for each test frequency. In addition, the antenna patterns at other specified elevations may be requested by the test conductor. Elevation pattern measurements shall be made with the azimuth on boresight at each test frequency. In addition, antenna patterns at other specified azimuths may be requested by the test conductor.

11. Record the following information for each pattern on the Antenna Radiation Pattern Measurements Data Sheet (Figure 5).

    a. Date, time, pattern number

    b. Antenna system number and description

    c. Antenna system configurations (polarization, elevation, test point, etc.)

    d. Boresight configuration (frequency, polarization, etc.)

    e. Environmental conditions

10. Azimuth pattern measurements shall be made with the elevation on boresight for each test frequency. In addition, the antenna patterns at other specified elevations may be requested by the test conductor. Elevation pattern measurements shall be made with the azimuth on boresight at each test frequency. In addition, antenna patterns at other specified azimuths may be requested by the test conductor.

11. Record the following information for each pattern on the Antenna Radiation Pattern Measurements Data Sheet (Figure 3).

    a. Date, time, pattern number

    b. Antenna system number and description

    c. Antenna system configurations (polarization, elevation, test point, etc.)

    d. Boresight configuration (frequency, polarization, etc.)

    e. Environmental conditions

DATA SHEET: ANTENNA RADIATION PATTERN MEASUREMENTS

Antenna Nomenclature: ______________________________

Test Pattern No.: ______________________ Date ______________

Comments: ______________________________________

Antenna Pattern Data Sheet Test Personnel ____________

Figure 5

1.10 ANTENNA POINTING CAPABILITY

1.10.1 Theory

The use of narrow beamwidth, high gain automatic tracking, telemetry antennas dictates the importance of accurate pointing and slave data information. Testing methods have been developed to accurately and quickly measure the parameters affecting the system capabilities and to provide the necessary information to the operator to allow him to determine parameter changes necessary to ensure optimum data recovery. The three tests (slew checks, points in space and solar tracking) test the most important parameters i.e. dynamic slave data, static slave data and pointing accuracy, as derived from the radar acquisition aids. Slew rates of 1°/second, 3°/second and 5°/second are required for both axes. One axis will be held constant for each series of dynamic checks while the other axis is exercised.

Dynamic slave tests indicate the telemetry antenna pointing lag or lead, as compared to the acquisition aid. From this testing, look ahead data may be preprogrammed to ensure rapid acquisition.

Point in space testing determines the relative error between the acquisition aid and the telemetry antenna at various ranges and may be used as a check on the slave system software. Solar tracking determines the pointing and slave designate errors using the known position of the sun as a reference.

1.10.2 Test Procedures

Radar/Telemetry Antenna Slew Checks - The radar/telemetry antenna slew checks demonstrate the servo response characteristics for the telemetry antenna system. Also, these tests provide the acquisition bus time delay measured from the radar site to the telemetry antenna system.

Test Description: Perform data runs with the telemetry antenna slaved to the acquisition data bus.

Equipment Required:	Local Radar Site
	Telemetry Antenna System
	Slave Acquisition Data Bus
Personnel Required:	Technical Operations Test Director
	Radar Operator
	Telemetry Antenna Operator
	Computer Operator
	Site Test Conductor
Data Requirements:	Telemetry Antenna Punched Paper Tape
	Radar History Tape
	Data Reduction
	Radar Differences

Test 3 (1°, 3°, and 5° Slew Checks)

Step 1 - Test Director: Perform a communication check to ensure communication and equipment status at each site.

	Communication Network (go, no go)	System (go, no go)
Radar Operator		
Telemetry Antenna Operator		
Test Conductor		
Computer Operator		

Step 2 - Test Conductor: Verify that the radar is sending acquisition data to the telemetry antenna via the slave system.

Step 3 - Test Conductor: Instruct the radar operator to position his antenna to 180° azimuth and 0° elevation.

Step 4 - Test Conductor: Ensure that the telemetry antenna system is in the slave mode of operation and azimuth is approximately 180° and 0° elevation.

Step 5 - Test Conductor: After Step 4 has been verified by the radar and telemetry antenna operator request the radar operator to slew at a 0.5/second rate to 0° azimuth. Reverse direction and slew to 360° azimuth, reverse direction immediately and return to 180° azimuth.

Step 6 - Test Conductor: After Step 5 has been completed, verify all recording stations have recorded the data from this run and annotate run number on tape.

Step 7 - Test Conductor: Obtain verification from the test director that a rerun of this test is not required.

Step 8 - Test Conductor: Repeat Steps 3, 4, 5, 6 and 7 for a 1.0/ second radar azimuth slew rate.

Step 9 - Test Conductor: Repeat Steps 3, 4, 5, 6 and 7 for 1.5/ second radar azimuth slew rate.

Step 10 - Test Conductor: After completion of Step 9 request the radar operator to position his antenna to 180° azimuth and +5° elevation.

Step 11 - Test Conductor: Ensure that the telemetry antenna system is in the slave mode of operation and the azimuth is approximately 180° and +5° elevation.

Step 12 - Test Conductor: After Step 11 has been verified by both operators request the radar operator to slew up at a 0.5/second elevation rate to +85° elevation and reverse direction and return to +5 elevation.

Step 13 - Test Conductor: After Step 12 has been completed verify all recording stations have recorded the data for this run and annotate run number on tape.

Step 14 - Test Conductor: Obtain verification from the test director that a rerun of this test is not required.

Step 15 - Test Conductor: Repeat Steps 11, 12, 13, and 14 for 3°/second radar elevation slew rate.

Step 16 - Test Conductor: Repeat Steps 11, 12, 13 and 14 for 5°/second radar elevation slew rate.

Step 16 - Test Conductor: Repeat Steps 11, 12, 13 and 14 for 5°/second radar elevation slew rate. NOTE: All reduced data from these tests should be forwarded to the RTSC Performance Analysis Department (PA300) at Vandenberg AFB, Ca.

Step 17 - Test Conductor: Request test director to release the radar operator from further testing after test director approves the testing conducted.

Points in Space - The radar antenna will designate the telemetry antenna to the azimuth and elevation points provided on data sheet 1. The radar octal readout and the telemetry antenna binary readout will be recorded for each point in space.

Equipment Required: Radar System
Telemetry Antenna
Antenna Slave System

Personnel Required: Radar Operator
Site Test Conductor
Technical Operations Test Director
Telemetry Antenna Operator
Computer Operator

Test 1 (Point in Space)

Step 1 - Test Director: Perform a communication check to ensure communication and equipment status at each site.

	Communication Network (go, no go)	System (go, no go)
Radar Operator		
Telemetry Antenna Operator		
Computer Operator		
Test Conductor		

Step 2 - Test Conductor: Direct the radar to 0° elevation, 0° azimuth and range to 32,000 nautical miles.

Step 3 - Test Conductor: Verify that the telemetry antenna is operating in the slave mode. Verify that radar has designated the telementry antenna system to 0° elevation and 0° azimuth.

Step 4 - Radar Operator: Reports decimal readouts for 0° elevation, 0° azimuth.

Step 5 - Test Conductor: Request the binary readouts for elevation and azimuth from the telemetry antenna system. Decimal readouts are required if the decimal display units have installed.

Step 6 - Test Conductor: Repeat Steps 4 and 5 until all azimuth points in space are completed for the 0° elevation.

Step 7 - Test Conductor: Direct the radar operator to designate the radar to 15° elevation and 0° azimuth and repeat Steps 4, 5 and until all azimuth points in space for 15° elevation have been recorded.

Step 8 - Test Conductor: Repeat Steps 4, 5, 6, and 7 for elevations to 30°, 45°, 60°, 75°, 80° and 85°.

Step 9 - Test Conductor: Request from the test director if further tests are required.

Step 10 - Test Conductor: Verification of Step 9 by the test director completes this test. Release all personnel and equipment associated with the test.

Solar Tracking - The test objective is to determine the bias between the radar slave bus and the telemetry antenna system. In addition, shaft encoder readout bias will be measured by comparing pointing data to the proven sun's position. This is accomplished by requiring the radar to autotrack the sun and designating the telemetry antenna to an equivalent point in space via slave data bus.

Equipment Required: Radar System
Telemetry Antenna System
Slave Data Bus

Personnel Required: 1 Radar Operator
1 Test Conductor
Telemetry Antenna Operator

Data Requirements: Punch TAPE and Radar/Telemetry Difference TAB (All reduced data will be provided to RTSC Performance Analysis Department (PA300) Vandenberg AFB, CA. for evaluation.)

Data Item	Description
104	Digital Magnetic Tape - Radar orientation record.
292	TM Antenna orientation punched paper tape record.
234	Digital Magnetic Tape - converted from data item 292.
241	Antenna orientation tab listing - octal dump.
351	Radar/TM antenna orientation difference tab listing - produced from data items 234 and 104.

1.11 TELEMETRY SIGNAL STRENGTH CONVERSION PROCEDURE

1.11.1 Theory

An important parameter in predicting the data quality of telemetry links is the received power density at the telemetry receiving antenna. This parameter, J_a, is the power flux density measured in watts per square meter falling on the antenna with matching polarization. The term J_a is related to the transmitted power by:

$$J_a = \frac{P_t G_t \Gamma}{4\pi d^2} \tag{1}$$

where:

J_a = Power flux density at the receiving antenna in watts/M^2

P_t = Airborne transmitter power radiated in watts

G_t = Airborne antenna gain

Γ = Polarization factor between transmitting and receiving antenna

d = Distance from airborne transmitter to receiving antenna in meters

The polarization factor, Γ, is dependent upon the coupling between the transmitting antenna and the receiving antenna and may vary between 0 and 1. In the case where one antenna is circularly polarized and the other is linear, the polarization factor is 0.5, which is a good approximation in any case.

The power flux density falling on a receiving antenna may also be determined from calibrated signal strength recordings using the following relationship:

$$J_a = S_i \frac{4\pi}{\lambda^2} \frac{EL_1}{G_r} \tag{2}$$

where:

S_i = calibration input signal in dBm

E = calibration error (equal to 1 in directional coupler systems)

L_1 = cable loss between the antenna and paramp input (dB)

G_r = receiving antenna gain (dB)

λ = wavelength of the received signal frequency, in meters

In addition to the normally expected signal strength calibration errors there exists a calibration bias affecting systems that use a coaxial switch for calibration signal injection. This bias occurs because the system noise temperature (hence system noise power level) referred to the preamp input is higher in the calibrate mode than in the operation mode. Thus, for a given signal level at the preamp input during calibration, there will be a lower receiver AGC voltage (indicating a higher signal) than would be obtained for the same signal level at the preamp input during the operate mode. Therefore, during the operating mode the recorded signal strength calibrations will indicate less (by the bias factor) signal than is actually being injected at the preamp input. These calibration bias errors are a function of system noise temperature, hence Figure of Merit, and can be expressed as follows:

$$E = 1 + \frac{290 - T_A}{T_S} \tag{3}$$

NOTE: There is no calibration bias ($E = 1$) for systems using a directional coupler for injecting calibration signals to the receiving system.

where: T_S = system noise temperature in °K, referred to the antenna feed, system in the operate mode

T_A = resultant antenna noise temperature, in °K, on cold sky, referred to the antenna feed. $T_A \approx 40°$ and 60°K for VHF antennas in the 2.2 GHz and 1.4 GHz regions respectively.

In the telemetry UHF region between 2.2 and 2.3 GHz, equation (2) has been simplified to yield the expression:

$$J_a(\text{dBm}) = S_i(\text{dBm}) + 20 \text{ Log } f + E \text{ (dB)} + L_1 \text{ (dB)} - G_r(\text{dB}) - 158.5 \quad (4)$$

where the factor - 158.5 is the evaluation of the $\frac{4\pi}{c^2}$ term.

where c^2 is a conversion term used to convert freqeuncy to λ, wavelength. If the desired units for J_a are watts, it is only necessary to add 30 dB (conversion from dBm to dBw) and take the antilog of expression (4).

Even though the calibration bias error, E, is identified above, there is an additional receiver AGC circuit error which is more difficult to model. AGC response is a measure of $\frac{S+N}{N}$ and it cannot be assumed that the circuit performs a linear addition of noise and signal power. Fortunately, a simple constraint can be made so that AGC or signal strength records can be easily converted to J_a values. When the signal power is 9 dB or more above the system noise the calibration bias error (both E and the AGC circuit error) becomes small enough to ignore; i.e., $\frac{S+N}{N} \approx S/N$. Therfore, directional coupler and coaxial switch calibrations are equally valid. For the following conversion charts E = 1 for all systems, λ is the center frequency of the band (either 2250 MHz or 265 MHz), and the L_1 and G_r are published values from the following reference:

Systems Performance and Accuracy Report, Vandenberg AFB, California: Space and Missile Test Center (AFSC), May 1977.

1.11.2 Conversion Chart

To facilitate the conversion procedure in the UHF telemetry band at SAMTEC stations, the following conversion charts have been prepared. To determine the J_a for a given antenna system, select the proper chart and read the calibrated signal strength on the vertical axis. Move horizontally till the diagonal line is intersected then move vertically down to the horizontal scale and read the J_a in watts per square meter.

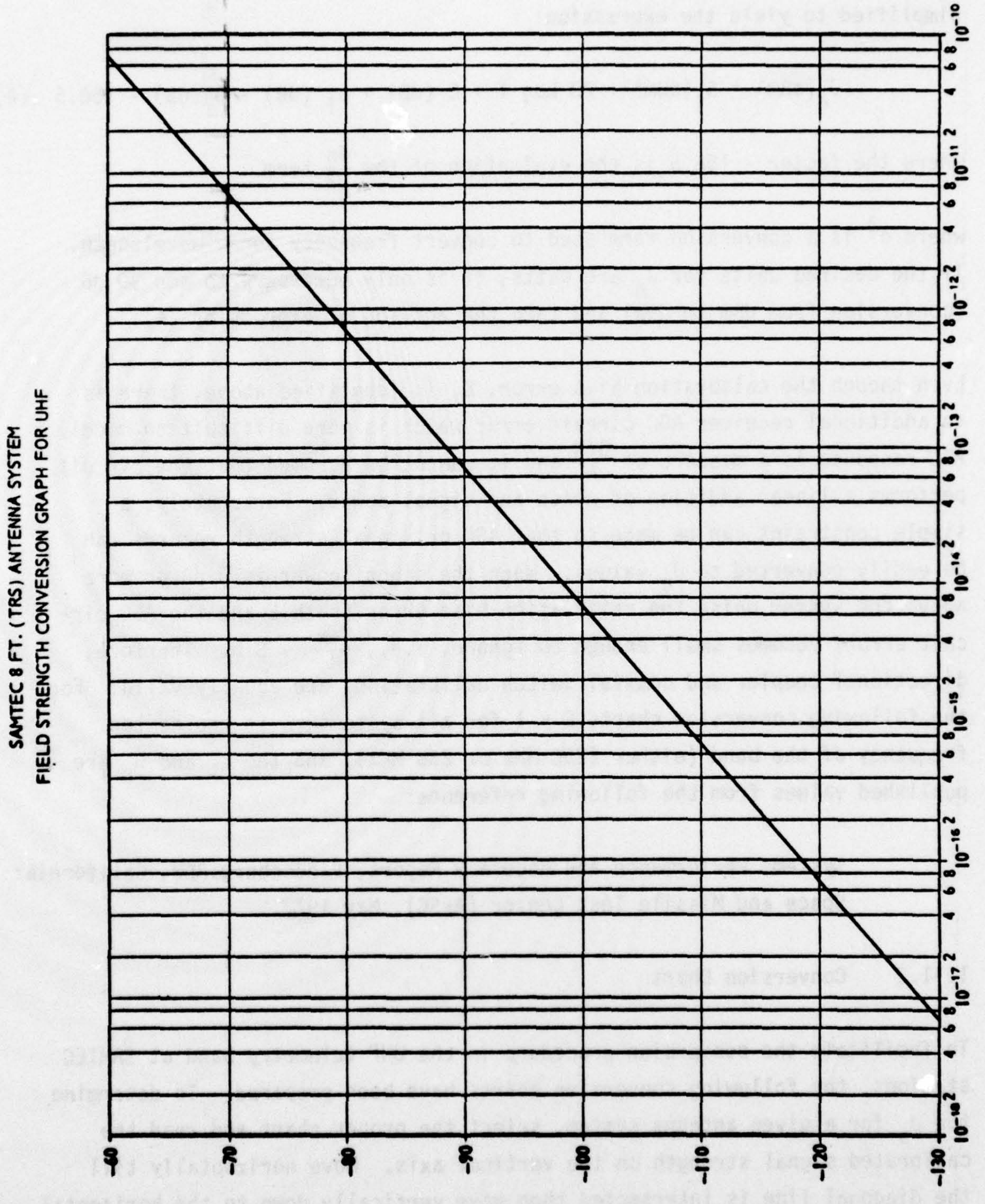

SAMTEC 8 FT. (TRS) ANTENNA SYSTEM
FIELD STRENGTH CONVERSION GRAPH FOR UHF
ANTENNA FIELD STRENGTH, Watts / M^2 (J_a)
PRE-AMP CALIBRATED INPUT - dBm (SI)

Figure I

SAMTEC 30 FT. (TRS) ANTENNA SYSTEM
FIELD STRENGTH CONVERSION GRAPH FOR UHF

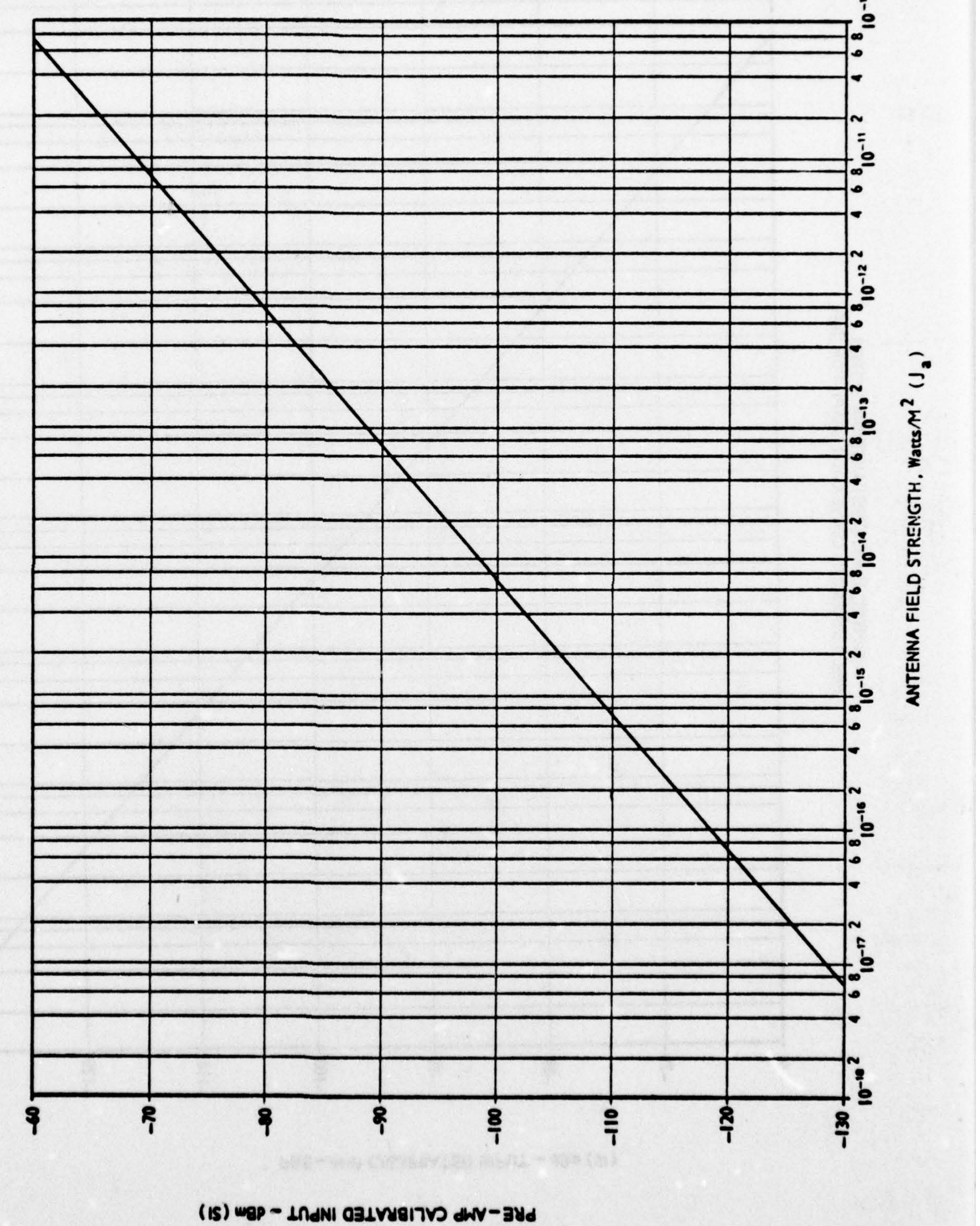


Figure 2

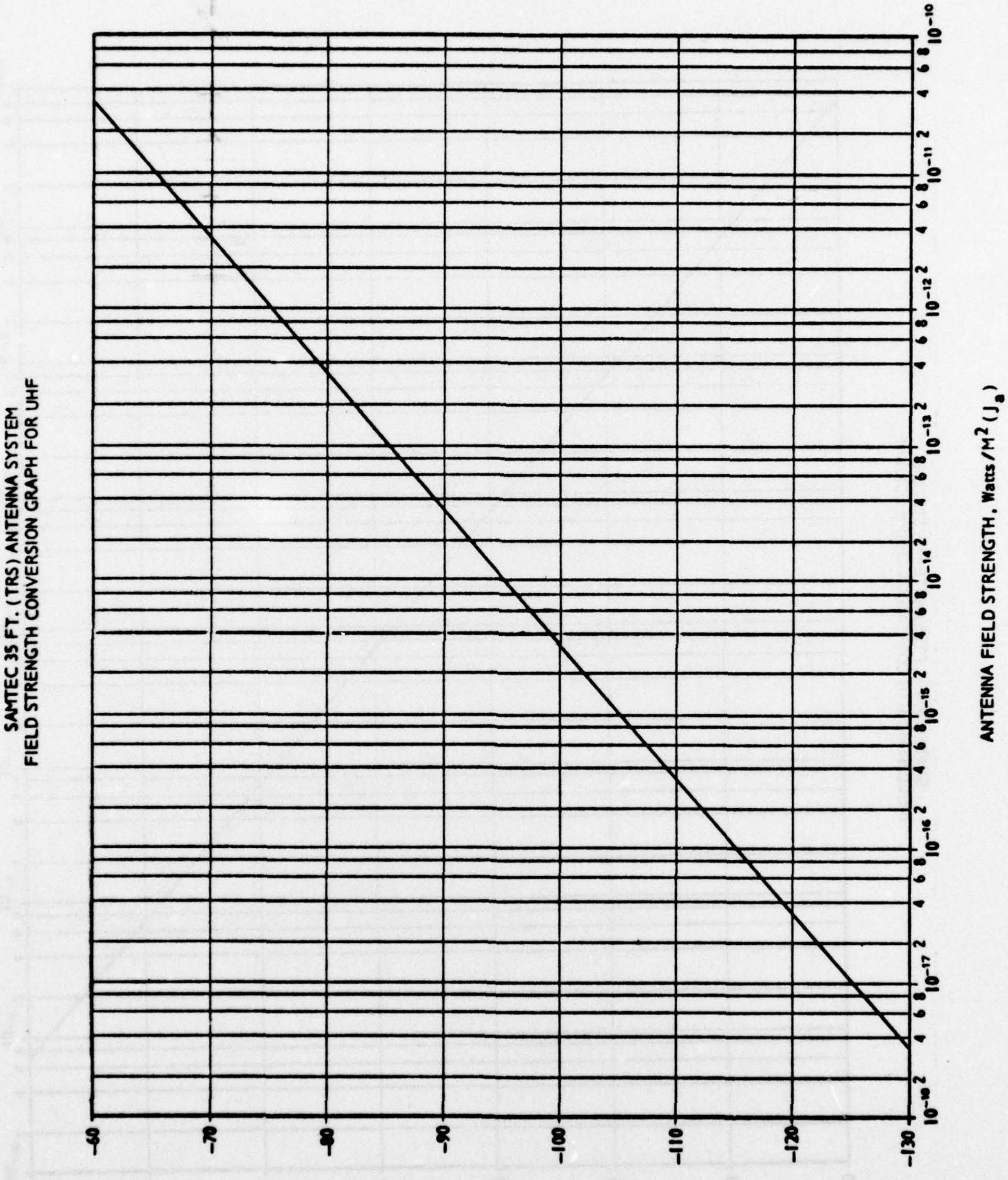

SAMTEC 35 FT. (TRS) ANTENNA SYSTEM
FIELD STRENGTH CONVERSION GRAPH FOR UHF
PRE-AMP CALIBRATED INPUT – dBm (SI)
-60
-70
-80
-90
-100
-110
-120
-130
ANTENNA FIELD STRENGTH, Watts/M^2 (J_a)
10^{-18}
10^{-17}
10^{-16}
10^{-15}
10^{-14}
10^{-13}
10^{-12}
10^{-11}
10^{-10}

Figure 3

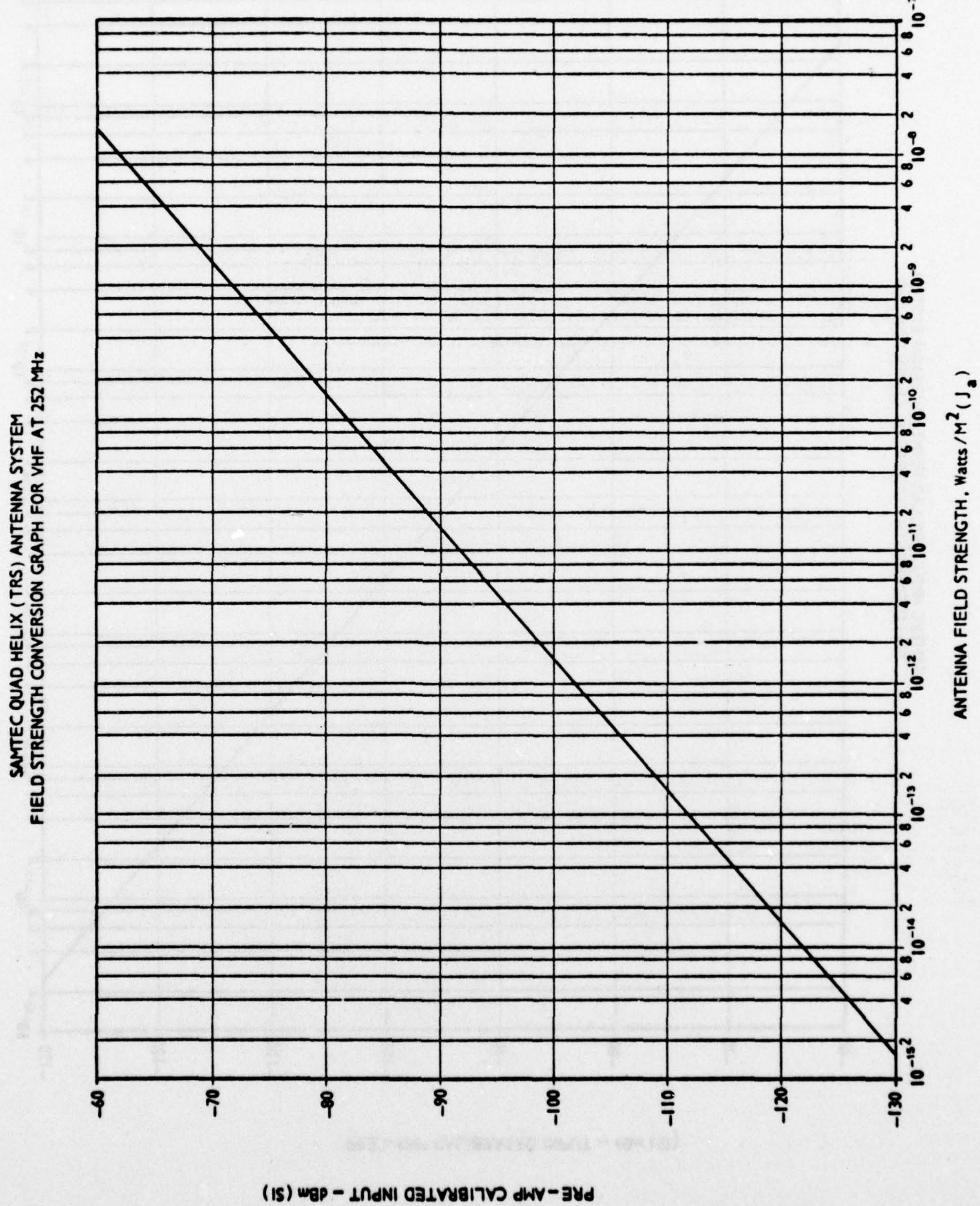

SAMTEC QUAD HELIX (TRS) ANTENNA SYSTEM
FIELD STRENGTH CONVERSION GRAPH FOR VHF AT 252 MHz
ANTENNA FIELD STRENGTH, Watts/M^2 (J_a)
10^{-15}
10^{-14}
10^{-13}
10^{-12}
10^{-11}
10^{-10}
10^{-9}
10^{-8}
10^{-7}
-60
-70
-80
-90
-100
-110
-120
-130
PRE-AMP CALIBRATED INPUT - dBm (SI)

Figure 4

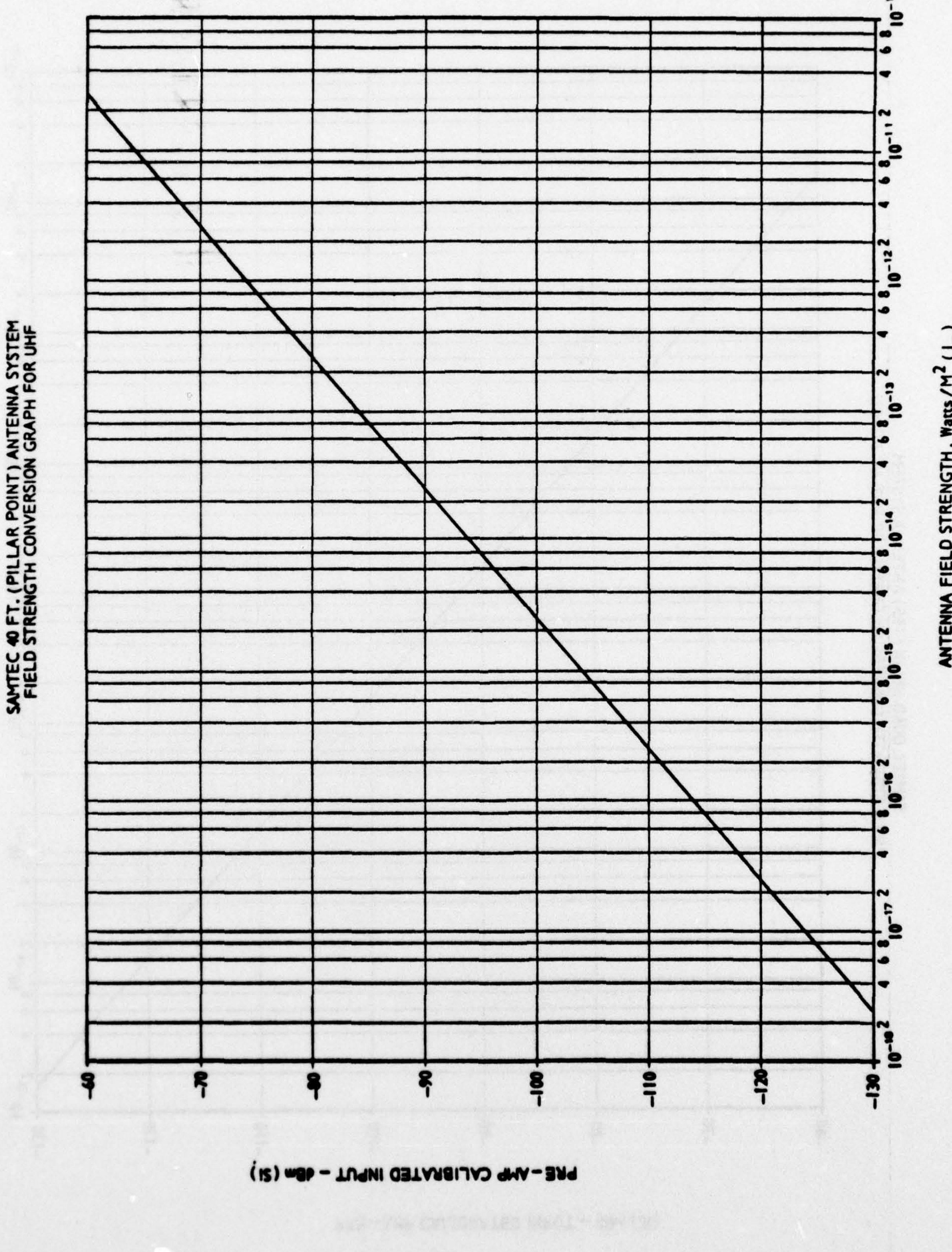

SAMTEC 40 FT. (PILLAR POINT) ANTENNA SYSTEM
FIELD STRENGTH CONVERSION GRAPH FOR UHF
-60
-70
-80
-90
-100
-110
-120
-130
PRE-AMP CALIBRATED INPUT - dBm (SI)
10^{-18} 2 4 6 8 10^{-17} 2 4 6 8 10^{-16} 2 4 6 8 10^{-15} 2 4 6 8 10^{-14} 2 4 6 8 10^{-13} 2 4 6 8 10^{-12} 2 4 6 8 10^{-11} 2 4 6 8 10^{-10}
ANTENNA FIELD STRENGTH, Watts/M^2 (J_a)

Figure 5

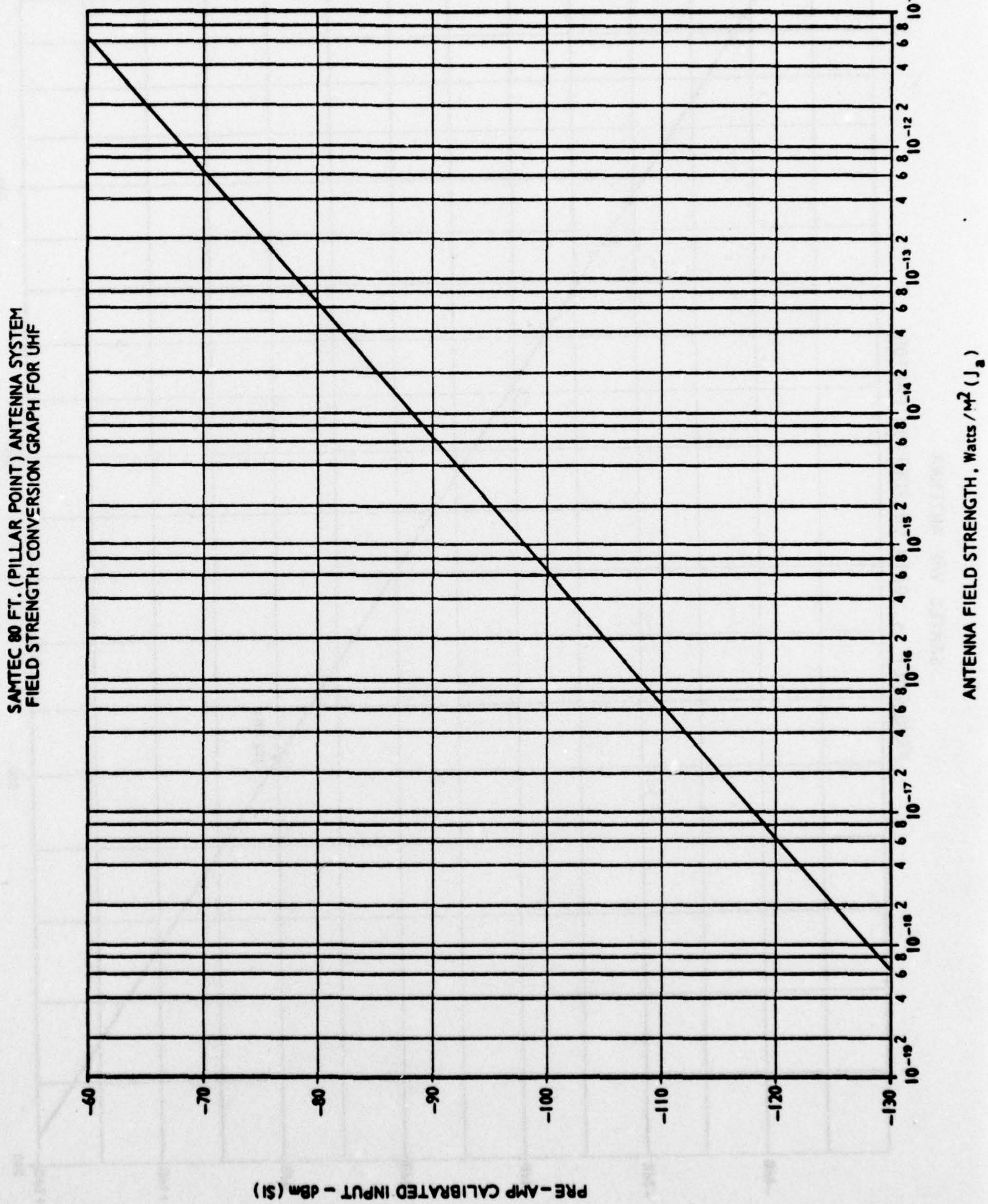
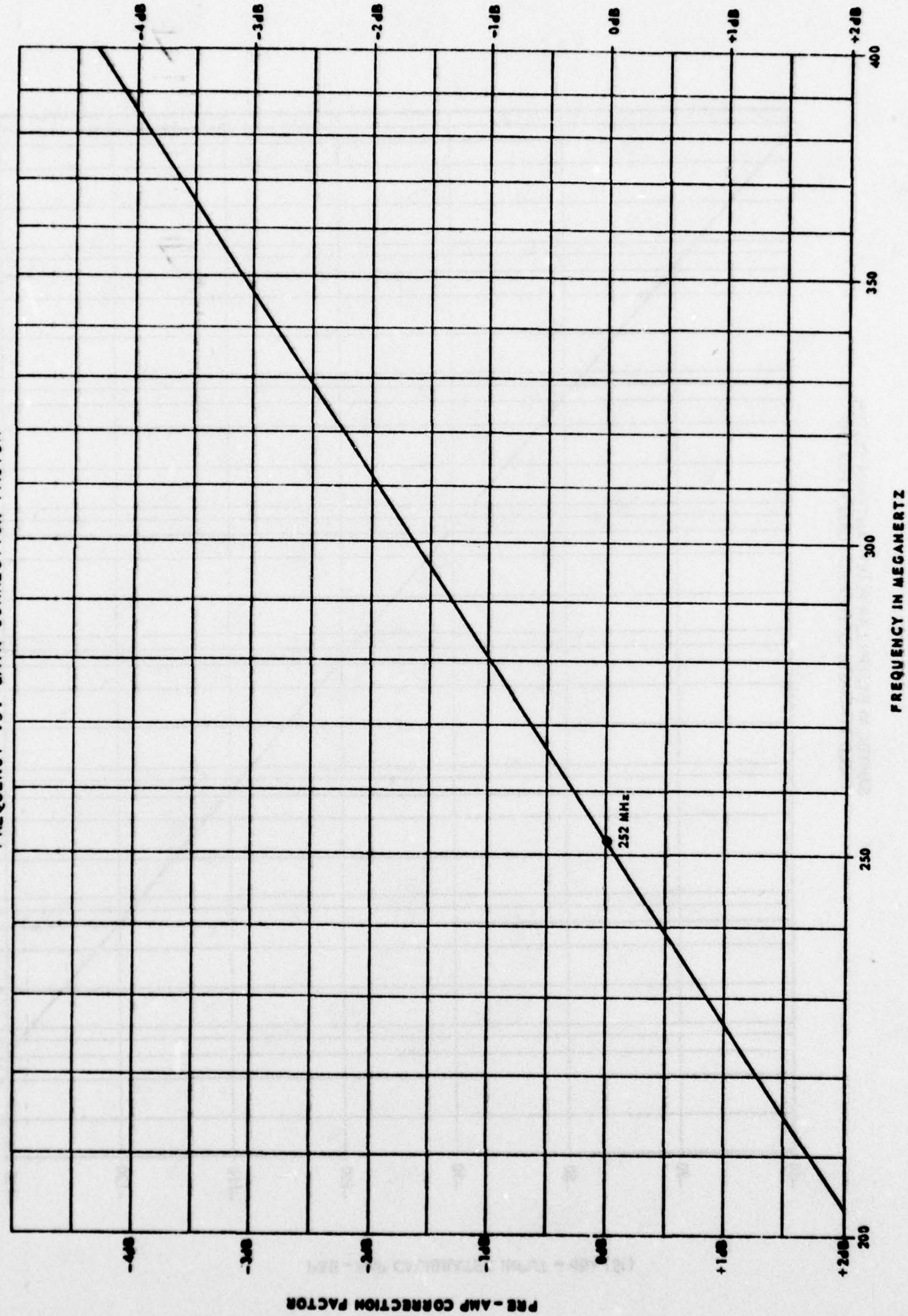

SAMTEC 80 FT. (PILLAR POINT) ANTENNA SYSTEM
FIELD STRENGTH CONVERSION GRAPH FOR UHF
PRE–AMP CALIBRATED INPUT – dBm (SI)
-60
-70
-80
-90
-100
-110
-120
-130
ANTENNA FIELD STRENGTH, Watts/M² (J_a)
10⁻¹⁹
10⁻¹⁸
10⁻¹⁷
10⁻¹⁶
10⁻¹⁵
10⁻¹⁴
10⁻¹³
10⁻¹²
10⁻¹¹

Figure 6

SAMTEC VHF ANTENNA

FREQUENCY vs. GAIN CORRECTION FACTOR



NOTE: 1. Curve is centered at 252 MHz

Figure 7

SECTION 2
MICROWAVE SYSTEMS

The Telemetry Microwave Wide Band Data System is the interface between the telemetry receiver/test facilities and the Range Data Facility (RDF) located at Building 7000, VAFB. The system provides the capability to relay real-time telemetry data or test signals from the acquisition receive sites and launch sites to the RDF for reduction and/or evaluation. A block diagram of interfaced sites is shown in Figure 1; bandwidth and frequency spectrum data are shown in Figure 2.

Testing and evaluation of the microwave system is accomplished using either pre-D or post-D data test methods depending upon the site originating the test signals (see Fig. 2). The test sequence for PCM and FM/FM data is generally the same as that for the receive sites (refer to test procedure in Section 1, Bit Error Rate, and Notch Noise Testing). In addition, harmonic distortion testing and time delay tests are conducted. The time delay test is not a qualitative test, but is used to determine data delay times for the data source selector which provides corrected timing for real-time relayed data. Reference material on test methods and test results includes:

1. Report No. P100-72-33, Test Procedure for Microwave Evaluation, Space and Missile Test Center, Vandenberg AFB, California, 18 June 1972.
2. Report No. P100-73-03, Evaluation of Pillar Point Microwave Testing, Space and Missile Test Center, Vandenberg AFB, California, 8 February 1973.
3. Report No. P100-73-04, Simultaneous Usage of Microwave Channels for Data Relay, Space and Missile Test Center, Vandenberg AFB, California, 8 February 1973.
4. Report No. P100-73-53, Linear Signal Inputs to Microwave Data Transmission Systems, Space and Missile Test Center, Vandenberg AFB, California, 24 December 1973.
5. Report No. P100-74-24, High Bit Rate PCM Investigation, Space and Missile Test Center, Vandenberg AFB, California, 11 April 1974.

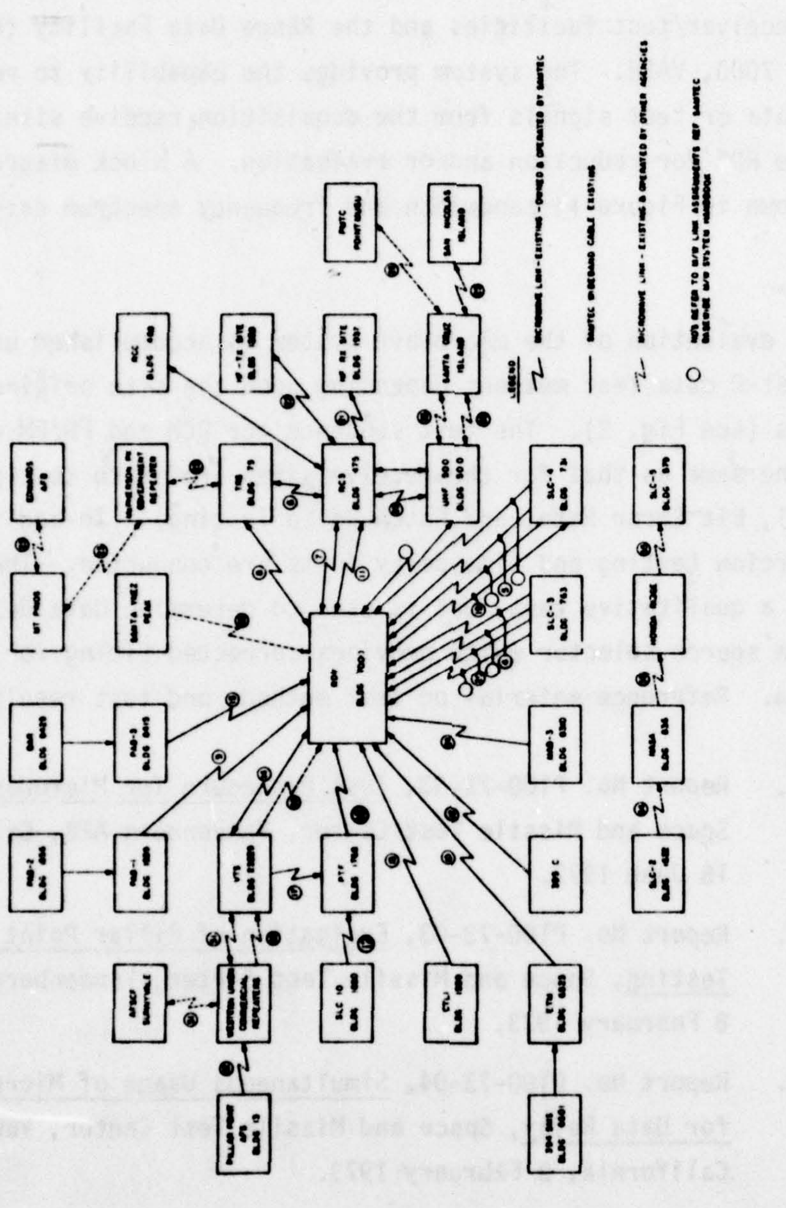


Figure 1 VAFB Telemetry Distribution System

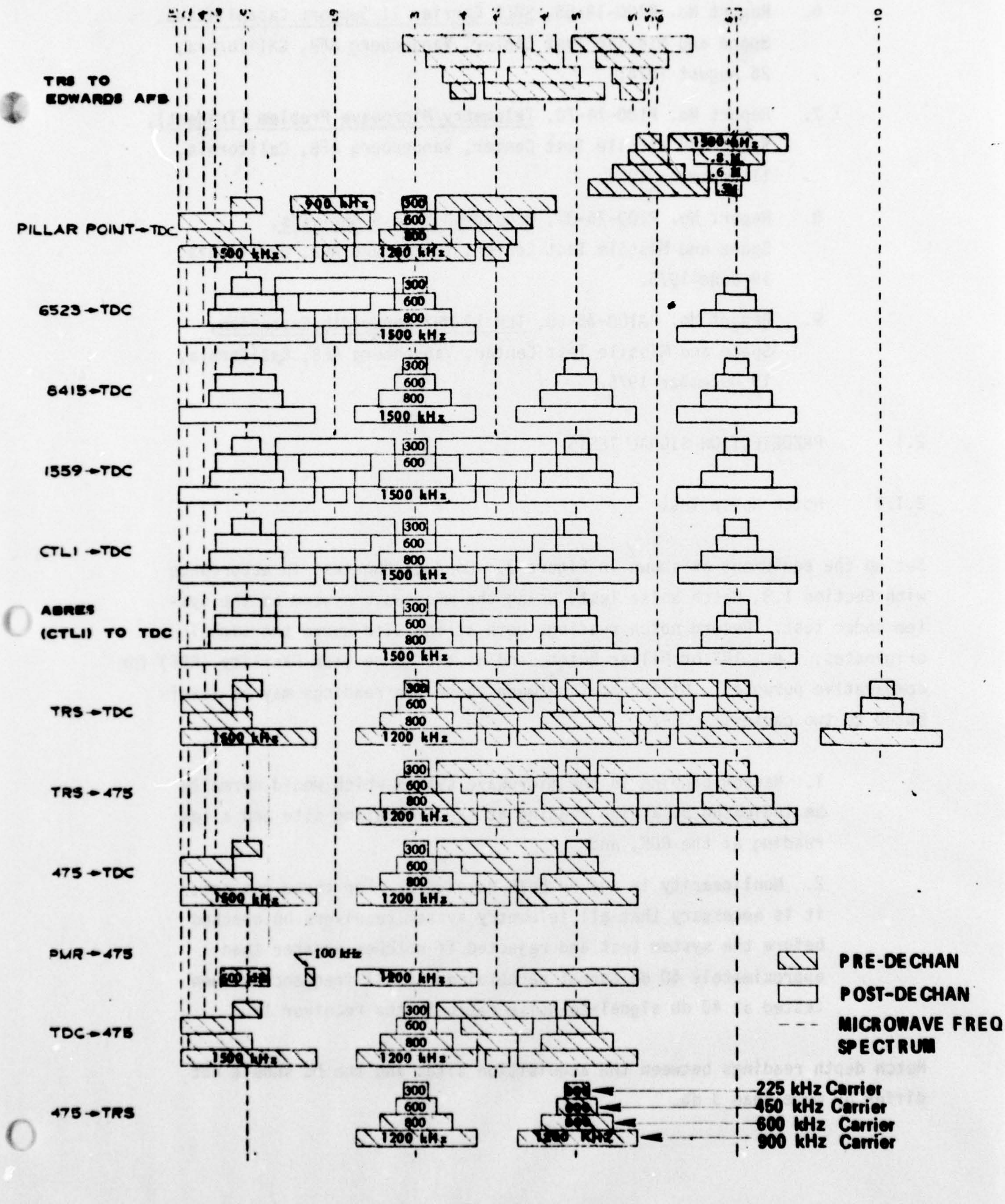


FIGURE 2 MICROWAVE SYSTEM

6. Report No. P100-14-55, SGLS Carrier II Support Capabilities, Space and Missile Test Center, Vandenberg AFB, California, 26 August 1974.

7. Report No. P100-74-70, Telemetry/Microwave Problem (Trident), Space and Missile Test Center, Vandenberg AFB, California, 11 November 1974.

8. Report No. P100-75-37, Minuteman Link 9 Analysis, Space and Missile Test Center, Vandenberg AFB, California, 19 June 1975.

9. Report No. PA100-75-68, TLM 10 MHz Bandwidth Expansion, Space and Missile Test Center, Vandenberg AFB, California, 19 December 1975.

2.1 PREDETECTION SIGNAL TESTS

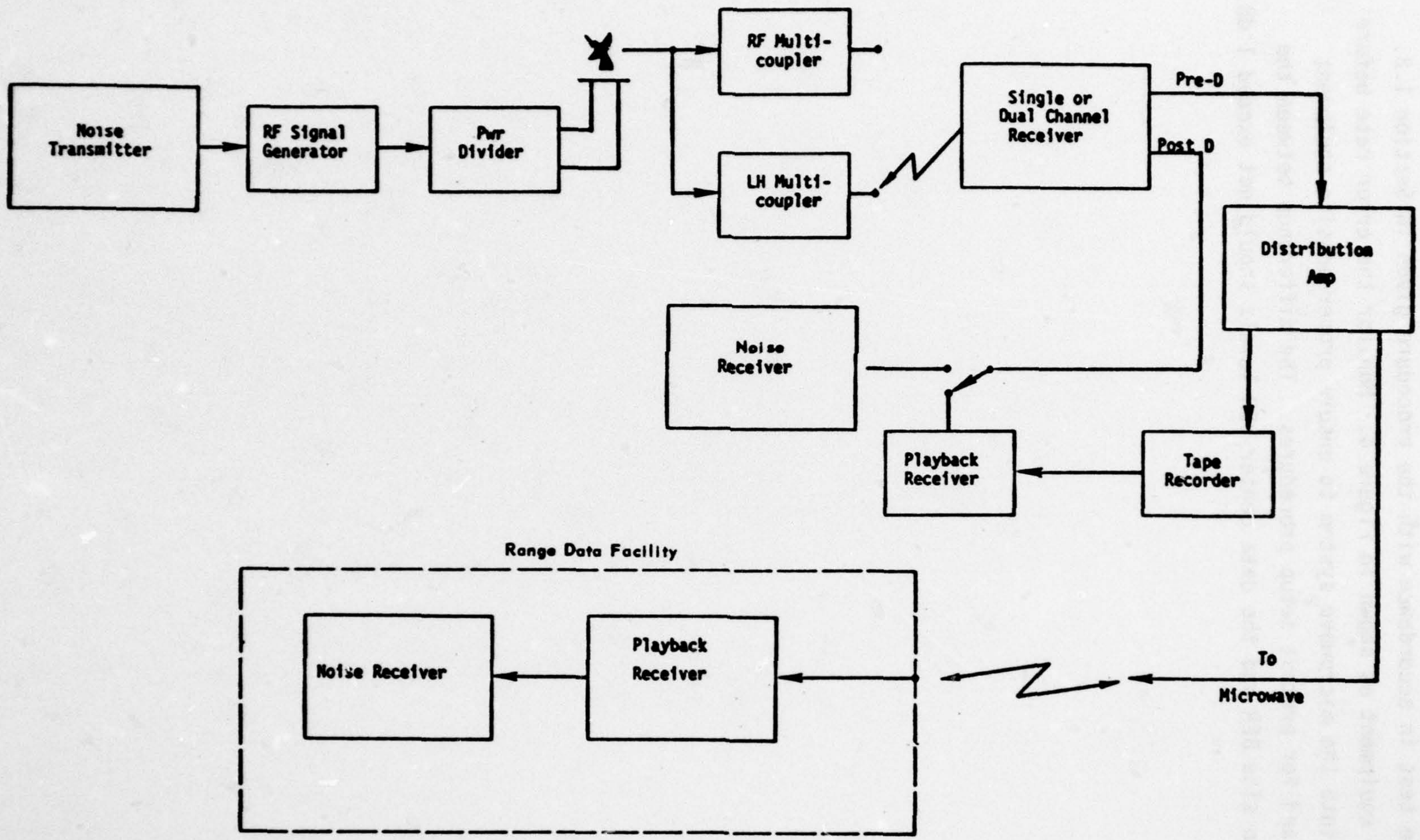
2.1.1 Notch Noise Test

Set up the equipment as shown in Figure 3. Conduct the test in accordance with Section 1.8, Notch Noise Test, using the microwave system as the system under test. Record notch readings both at the site where the signal originates, i.e., TRS or Pillar Point, and at the Range Data Facility (RDF) for comparative purposes. Differences between these two readings may be attributed to two causes:

1. Narrow banding in the microwave system which would normally be indicated by a high reading at the orginating site and a low reading at the RDF, and

2. Nonlinearity in one or both receivers. For these reasons, it is necessary that all telemetry system receivers be checked before the system test and rejected if notches greater than approximately 40 db cannot be obtained at all frequencies when tested at 40 db signal-to-noise ratio in the receiver IF.

Notch depth readings between the acquisition sites and the DC should not differ by more than 3 db.



NOTCH NOISE TEST CONFIGURATION NO. 3

2.1.2 Bit Error Rate Test

Conduct the test in accordance with the procedure given in Section 1.8. Set up the equipment as shown in Figure 4. Monitor the error rate before injection into the microwave system to ensure proper on-site equipment alignment and for pretest setup procedures. The difference between the acquisition site BER and the data center BER levels should not exceed 1 dB.

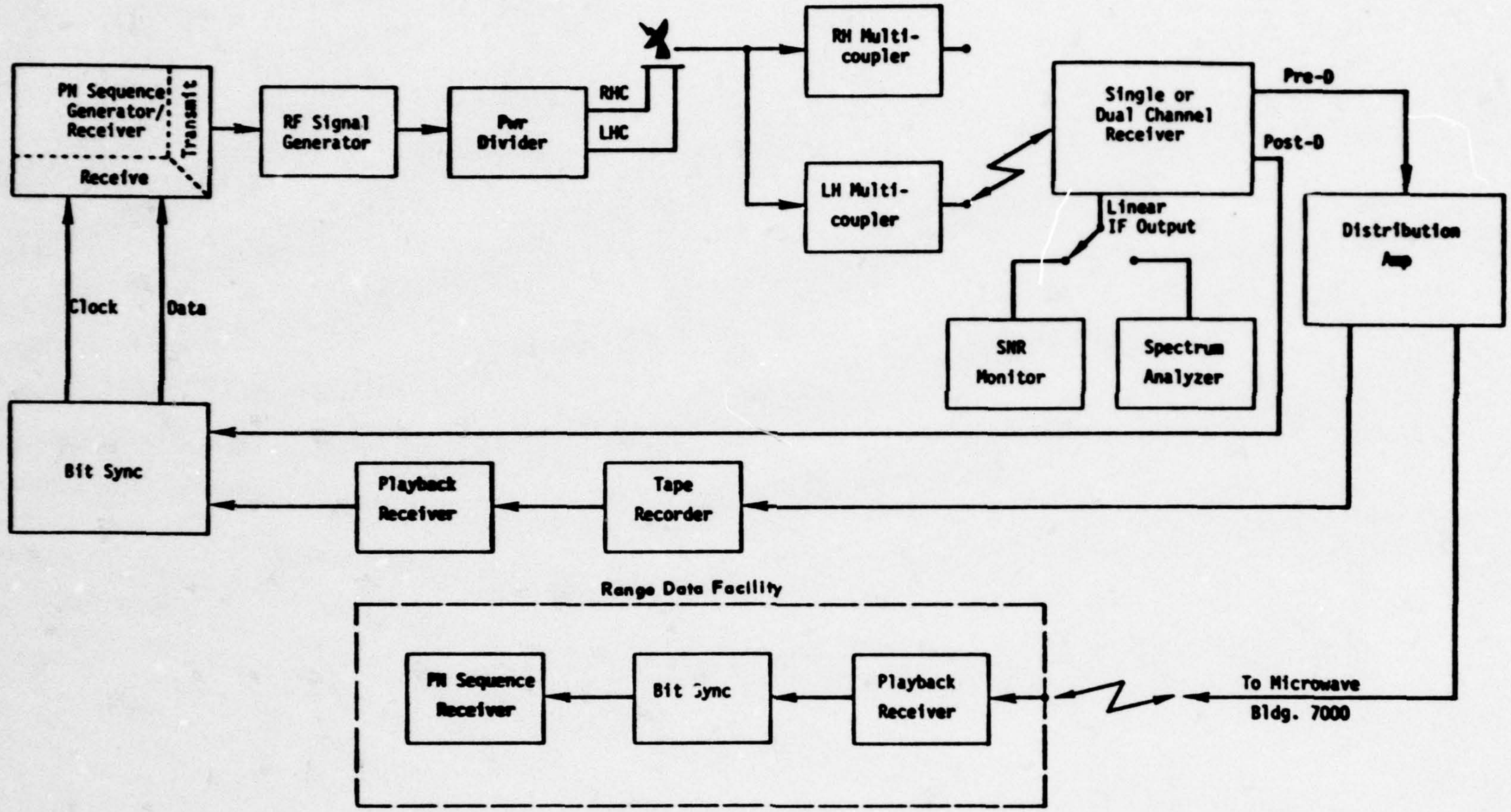


FIGURE 4 BIT ERROR RATE TESTING

2.2 POSTDETECTION SIGNAL TESTS

2.2.1 Notch Noise Test

Conduct testing as described in Section 1.8. The noise generator ouptut is injected directly into the microwave system and the microwave output is monitored by the noise receiver at Building 7000 at Vandenberg AFB. The input noise level to the microwave system is monitored with a true voltmeter and the level is maintained 0.75 volts. Pass/fail criteria is the same as for predetection data.

2.2.2 Bit Error Rate Test

Conduct this test as described in Section 1.8. Pass/fail criteria is the same as for predetection data.

2.2.3 Channel Harmonic Distortion

Set up the equipment as shown in Figure 1.

Adjust the spectrum analyzer for a 0-2 MHz display with log reference level at -30 dB. Other controls as follows:

Video Filter	-	100 Hz
Log/Linear	-	Log
Bandwidth	-	1 kHz
Scan Time	-	To Calibrate Display

Record total harmonic distortion at 100 kHz, 225 kHz, 400 kHz, 450 kHz and 600 kHz. Record 2nd and 3rd harmonic level (dB below fundamental) from the spectrum analyzer at the frequencies specified above.

2.2.4 Time Delay

Set up the equipment as shown in Figure 2. The 1 PPS will be a positive, on time pulse from the station time standard. Measure and record the time between the transmitted and local 1 PPS.

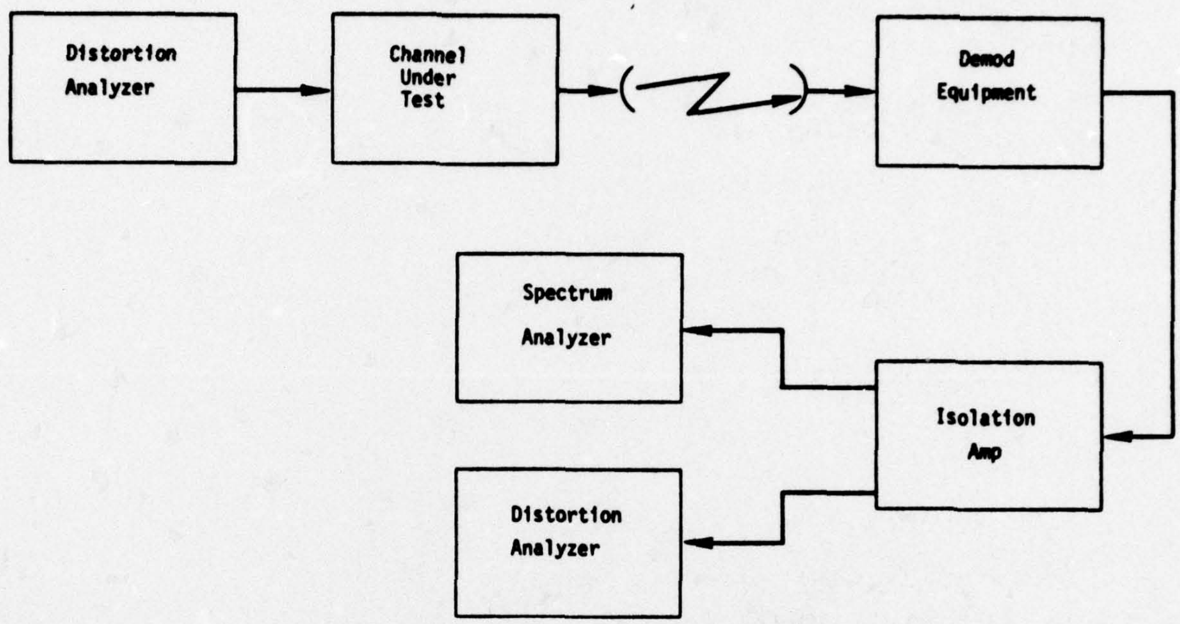


FIGURE 1 HARMONIC DISTORTION

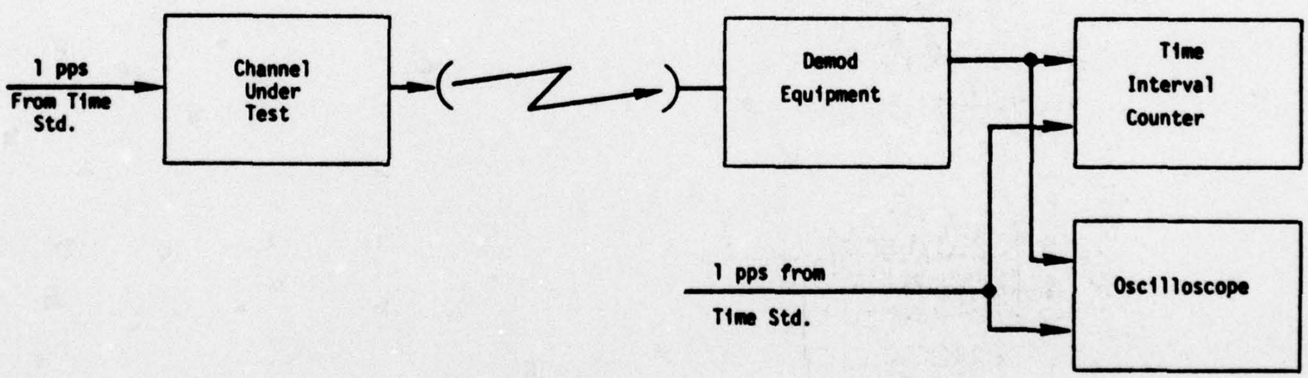


FIGURE 2 TIME DELAY MEASUREMENT

SECTION 3
DATA PROCESSING SYSTEMS

The purpose of this procedure is to minimize telemetry analog magnetic tape recorder compatibility problems and secondly enable the RDF data processing stations to perfrom front end (tape recorder, playback receiver and bit synchrnoizer) certification to ensure telemetry data quality. The procedure applies to all telemetry acquisition sites and data processing stations that use magnetic tape recorders for recording or reproducing telemetry data.

Analog magnetic tapes, even when played back on similar tape recorders, do not always produce quality data. Further, the industry has not standarized the head record gap and various other recorder parameters. Therefore, when playing back tapes on any machine (especially machines of another manufacturer or bandwidth), degradation occurs. This will be minimized by using the techniques in this procedure.

The tape signature provides a method of verifying the proper operation of equipment used to retrieve the recorded data (e.g., playback receivers and bit synchronizers). Special emphasis is placed on the playback receiver setup due to its complexity and almost total manual control required. In addition, changing of receiver plug-in modules is routinely made to process different types of data. The tape signature verifies correct interface of the various modules at the time of their use.

On all launch support operations, each telemetry acquisition site records tape signatures when pulse code modulation (PCM) predetection, PCM post-detection or hybrid formats are supported. No tape signatures are recorded when FM/FM predetection or postdetection data formats are supported. The signature is recorded on the tape leader. Either voice annotation recorded on the tape or a written description on the tape label attached to the tape reel is required to describe the tape signature.

The site that processes the flight tape is responsible for using the tape signature to verify tape recorder playback head alignment, the playback receiver setup and bit synchronizer operation for PCM. Verification of FM/FM data quality is made on the flight data itself.

Procedures for certifying the tape recorder, playback receiver and bit synchronizer performance are condensed from the recent RDF Improvement Program Report. BER checks are used for PCM formats while spectrum analysis is used to check the FM/FM format data quality. Pertinent references include:

Report P100-74-33, Telemetry Data Center Improvement, Vandenberg AFB, California: FEC Systems Performance Analysis Directorate, May 1974.

Pickett, R. B. and Schoeck, K.O. Front End Certification, International Telemetering Conference Proceedings, 1974.

3.1 FRONT END CERTIFICATION

3.1.1 Theory

The magnetic tape recorder has long been recognized as a highly potential source of data degradation which is aggravated to some extent by interplay problems existing not only between recorders of unlike manufacturer but also between recorders from the same manufacturer. In recognition of these problems, SAMTEC has initiated operating procedures to insure maximum compatability between all types of recorders. This has resulted in a significant reduction in lost manhours in processing time and has improved the quality of the end product. Although the interplay problem has not been completely eliminated, recent studies indicate that many of the data processing systems difficulties are still located within the recorder to digital system interface and many processing problems previously attributed to tape recorders were, in fact, caused by the playback receiver. Therefore, in an attempt to minimize the problems associated with these systems, without adding additional workload to the reduction facilities, new procedures have been designed which perform a functional front end check and provide the technician with a Go/NoGo criteria.

NOTE: This procedure applies to one half inch machines and one inch machines.

1. A segment of pseudo-random data is placed on each data recording track at the beginning of each tape at 10^{-5} Bit Error Rate (BER). The 10^{-5} BER leader should simulate the operational link as closely as possible. (i.e. Same bit rate, code type, carrier deviation and pre-d frequency). While recording this segment the acquisition site can verify its station set-up. Refer to Figure 2 for acquisition site configuration.

2. Set the recorder speed to normal operating speed for the operation.

3. Adjust signal generator output level to read 1 to 5 on the 10^{-5} scale on the error rate monitor.

4. Run the recorder to record 30 seconds of the pseudo-random data.

   NOTE: A separate 30 second tape signature is required for each link recorded.

Playback Site Procedures - Set up the playback receiver per following instructions 1 through 11 before playback of predetection data using a PM demod or instructions 12 to 16 for an FM demod.

1. If a PM demod is being used, set the search range on top of of the unit to 100 KHz prior to inserting the unit in the receiver.

2. Install the PM demod in the receiver.

3. Set the receiver OPERATE MODE switch to PBK.

4. Set the demodulator SEARCH switch to MANUAL and the ANTI-SIDEBAND switch OUT.

5. With no signal input to the receiver adjust the LOCK BAL control clockwise until the LOOP LOCK lamp is out.

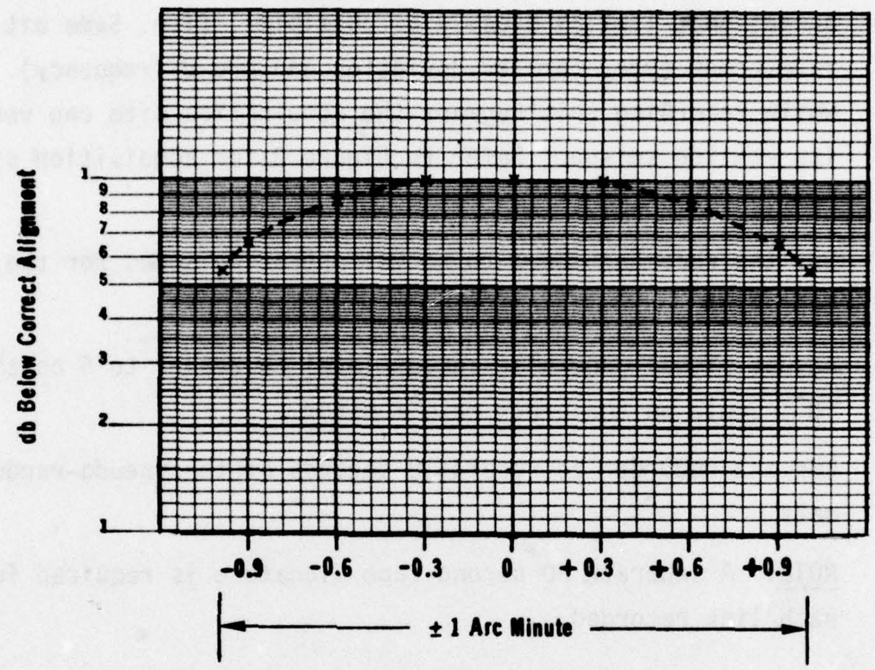
It has been found that the most critical recorder parameter affecting data quality is the head azimuth adjustment. It has also been found that this adjustment is more conveniently made using the recorder data output as an indicator and adjusting the heads to produce a maximum output. Frequency response was found to have very little effect on the data as long as it was within reasonable limits and it is recommended that these adjustments be considered only during routine maintenance. The effect of the head azimuth alignment is illustrated in Figure 1.

In considering the problems associated with the reduction of PCM or Hybrid Data, it was found that a pre-recorded bit error rate tape leader not only provided the signals necessary for head azimuth alignment but also provided a method to certify the playback receiver, bit synchronizer and associated signal routing equipment, including cabling and any signal amplifiers which may be used. This tape signature leader is a 30 second recorded interval at the beginning of each tape track containing pseudo noise (PN) PCM in the same format and code as the mission data.

The PCM leader is recorded at a receiver IF signal-to-noise ratio which produces a bit error rate of approximately one error per hundred thousand data bits (1×10^{-5}). During tape playback, if the leader data cannot be recovered with fewer than approximately ten errors (1×10^{-4}) per hundred thousand data bits, the system is considered to be in need of adjustment and the operator proceeds no further until he has adjusted his equipment to obtain this error rate. The following procedure outlines the necessary steps required in data processing front end certification.

3.1.2 Test Procedures

<u>Acquisition Site Signature Procedures</u> - The PCM signature described below will be recorded on the leader of each flight tape for PCM predetection, PCM postdetection, or hybrid data formats. No signature will be recorded for FM/FM predetection or postdetection formats. If more than one tape is necessary to cover the flight interval, all tapes will contain signatures.



Note: 1 arc minute misalignment results in approximately 4.5 db change in reproduce level, yet there is negligible change in bit error rate up to 1 Mbit. These measurements were compiled from many tests made on twelve of the operational ½ inch Model VR3700B analog tape recorder/reproducers at the SAMTEC.

Figure 1 Reproduce Output Level versus Head Azimuth Alignment

NOTE: This procedure applies to one half inch machines and one inch machines.

1. A segment of pseudo-random data is placed on each data recording track at the beginning of each tape at 10^{-5} Bit Error Rate (BER). The 10^{-5} BER leader should simulate the operational link as closely as possible. (i.e. Same bit rate, code type, carrier deviation and pre-d frequency). While recording this segment the acquisition site can verify its station set-up. Refer to Figure 2 for acquisition site configuration.
2. Set the recorder speed to normal operating speed for the operation.
3. Adjust signal generator output level to read 1 to 5 on the 10^{-5} scale on the error rate monitor.
4. Run the recorder to record 30 seconds of the pseudo-random data.

   NOTE: A separate 30 second tape signature is required for each link recorded.

Playback Site Procedures - Set up the playback receiver per following instructions 1 to 10 before playback of predetection data using a PM demod or instructions 12 to 16 for an FM demod.

1. If a PM demod is being used, set the search range on top of of the unit to 100 KHz prior to inserting the unit in the receiver.
2. Install the PM demod in the receiver.
3. Set the receiver OPERATE MODE switch to PBK.
4. Set the demodulator SEARCH switch to MANUAL and the ANTI-SIDEBAND switch OUT.
5. With no signal input to the receiver adjust the LOCK BAL control clockwise until the LOOP LOCK lamp is out.

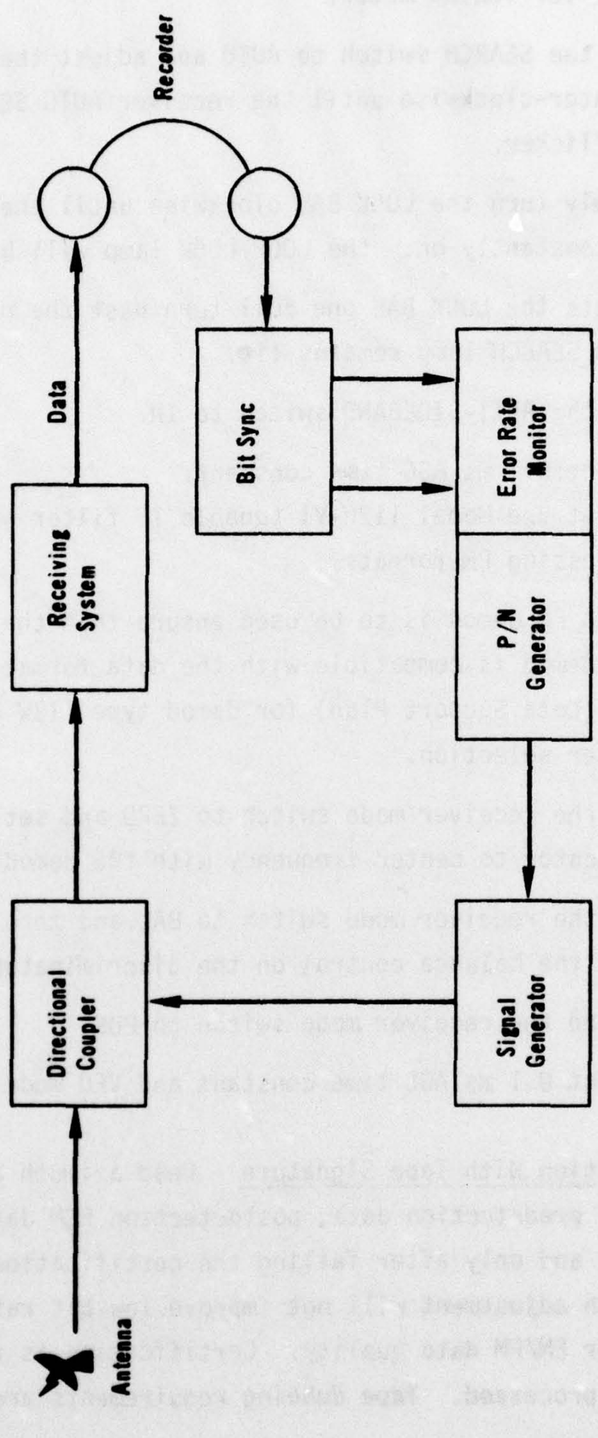


Figure 2 Acquisition Site Configuration

6. Adjust the NOISE BAL control for zero indication on the receiver TUNING meter.

7. Set the SEARCH switch to AUTO and adjust the LOCK BAL control counter-clockwise until the receiver AUTO SEARCH lamp begins to flicker.

8. Slowly turn the LOCK BAL clockwise until the AUTO SEARCH lamp is constantly on: the LOOP LOCK lamp will be out.

9. Rotate the LOCK BAL one full turn past the point at which the AUTO SEARCH lamp remains lit.

10. Set the ANTI-SIDEBAND switch to IN.

11. Select 0.1 ms AGC time constant.
Do not use Model 1120-VI tunable IF filter when processing PM formats.

12. If an FM demod is to be used ensure that the deviation range of the demod is compatible with the data format. Refer to the DSP (Data Support Plan) for demod type (IBW or WB) and IF filter selection.

13. Set the receiver mode switch to ZERO and set the tuning meter indicator to center frequency with the demod AFC control.

14. Set the receiver mode switch to BAL and zero the tuning meter with the balance control on the discriminator.

15. Return the receiver mode switch to PBK.

16. Select 0.1 ms AGC time constant and VFO mode for tuning.

Front End Certification With Tape Signature - Head azimuth adjustments are to be made only for predetection data, postdetection PCM data above 200 kbs and hybrid data and only after failing the certification check described below. Head azimuth adjustment will not improve low bit rate (below 200 kbs) postdetection PCM or FM/FM data quality. Certification is required only on the track being processed. Tape dubbing requirements are listed in a separate section.

1. After performing the setup procedures configure the system as shown in Figure 3. Run mission tape with tape signature leader and tune the receiver.

2. Run data tape signature at normal operating speed. Using head azimuth adjustment peak the reading on front panel meter on the track from which data is to be processed.

3. Check the BER count on the signature again. If a BER of 1×10^{-4} or better cannot be obtained, initiate corrective procedures.

Front End Certification Without Tape Signature - (FM/FM data only)

1. Display the postdetected data on a panoramic indicator or a spectrum analyzer. Set the analyzer IF bandwidth to 1 KHz or less.

2. Observe that the peaks of the highest frequency subcarriers are at least 30 dB above the noise floor and at least 30 dB above spurious frequencies such as cross products or interference. If not, initiate corrective procedures.

Due to spectrum analyzer frequency response limitations, the observations should be made on 10.5 kHz or higher frequency subcarriers. This procedure is not applicable to frequencies below 10 kHz due to spectrum analyzer limitations.

Tape Dubbing

1. Verify that the recorders are properly set up to record and reproduce. Verify the data quality of the tape being played by BER or spectrum.

2. The tape signature on the original tape can be dubbed. New signatures are not required.

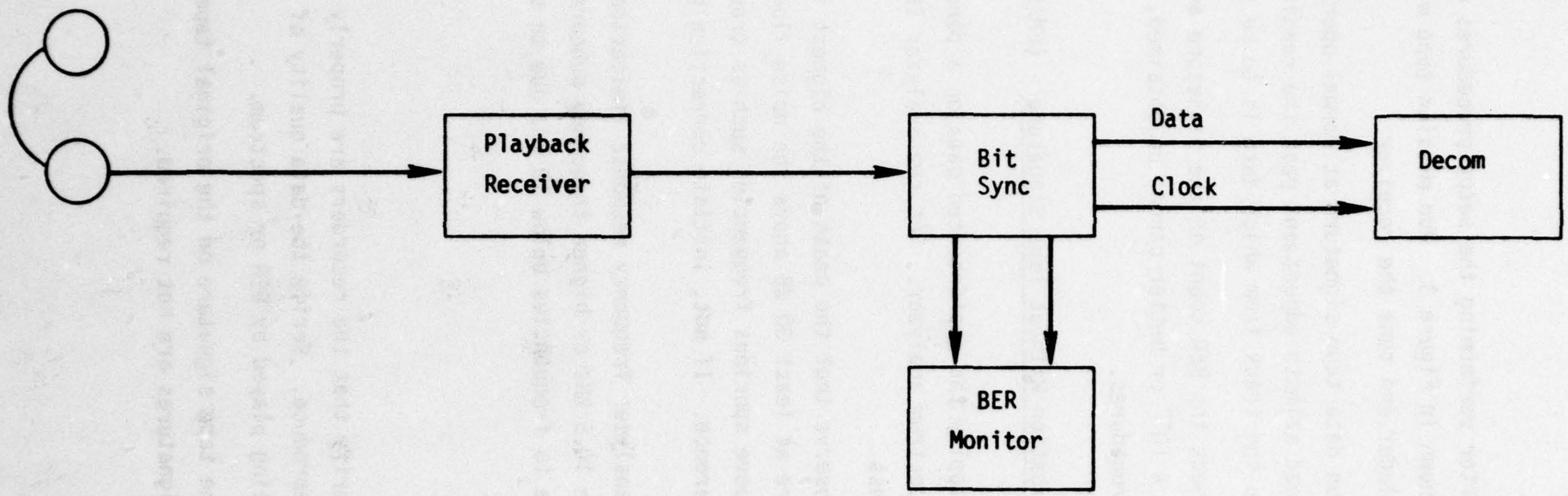


FIGURE 3 PLAYBACK SYSTEM CONFIGURATION

3.2 DATA SOURCE SELECTOR VALIDATION

3.2.1 Theory

The primary functions of the data source selector (DSS) are:

- Demodulation and signal conditioning of pre-d PCM telemetry data.
- Time synchronization of 2, 3 or 4 PCM telemetry data streams.
- Selection, on a bit by bit basis, of the best data source to produce a single best source data output.
- Time correlation, to refer the best source data output time to that of its arrival at the telemetry source station designated as the master station.

These functions are accomplished in four major subsystems:

1. The Input subsystems convert the pre-d PCM data to conditioned parallel digital words compatible with the control and memory units.
2. The Signal Quality Measurement subsystems determine the signal-to-noise ratio (SNR) and the relative data quality of each input data stream. Relative data quality is composed of signal-to-noise ratio, bit synchronizer lock status and frame synchronizer lock status. The resultant digital representations are presented to the memory unit for storage along with their corresponding data.
3. PCM data synchronization is accomplished in the Time and Space Mapping subsystems. These subsystems consist of the memory unit, logic and control function and basic timing circuitry. The timing circuitry ensures that incoming data is synchronized to the DSS clock even through periods of complete signal loss on all input channels. The DSS memory facilitates the storage of incoming data in such a manner that time synchronization of all valid input channels is effected. Time code correction circuitry is incorporated

in the control unit. Timing signals input to the DSS are delayed an appropriate amount to account for data propagation delays between the receiving site and the DSS input, and also to account for delays internal to the DSS. The DSS output merged data stream is therefore time tagged as though it were received at the master telemetry receive site, regardless of the actual receive site and regardless of additional propagation delays due to site locations.

4. The Output subsystem computes the correct value of each data bit based on the SNR value. If the bit synchronizer or frame synchronizer of one channel is not locked, the SNR word from that channel is disabled so that "bad" data carries no weight in the decision. The final output of the system is then a serial PCM merged data stream. A corrected serial time code (IRIG-A(ac) or IRIG-B(ac) is selectable) is also available for correlation of the data.

3.2.2 Test Procedures

Signal Quality Monitor (SQM) - Before verification testing and calibration, it is necessary to ensure that the SQM modules are properly aligned according the the manufacturers specifications. The alignment procedure for the SQM is located in Helix Document No. 10900003, Operation and Maintenance Manual, Volume I and II. Detailed alignment procedures are contained in paragraphs 3.4 through 3.4.7. These procedures should be accomplished on a bi-monthly basis until sufficient confidence in the system is demonstrated at which time a quarterly alignment should be sufficient.

Signal-To-Noise Ratio Calibration:

1. Set up the equipment as shown in Figure 1.
2. Set both step attenuators to 0 db.
3. Adjust the oscillators to 900 kHz and 901 kHz at 0.75 volts output respectively.
4. Sum the two oscillator signals using a 50 Ω "T" connector and connect this signal to the pre-d playback unit.

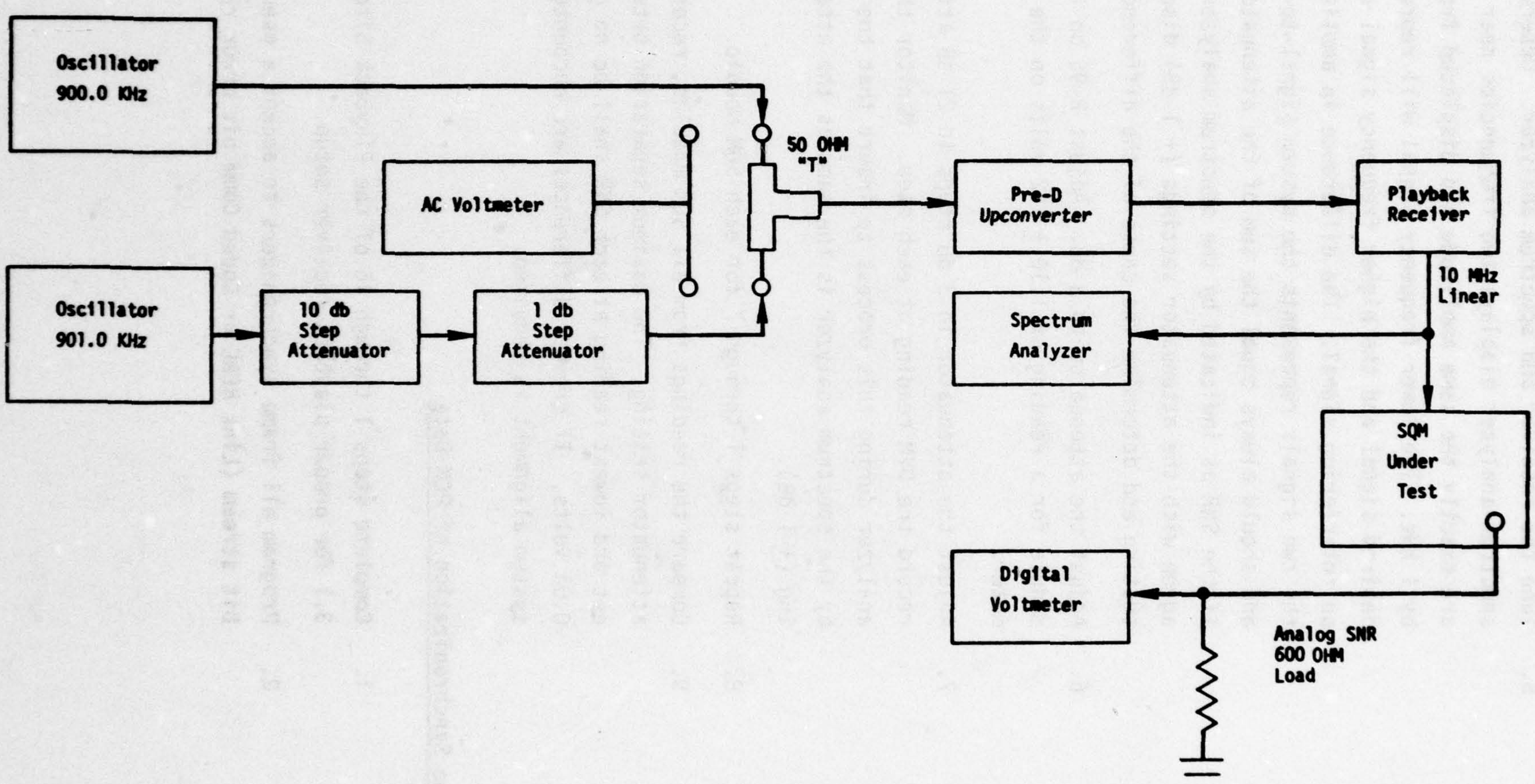


FIGURE 1 SNR CALIBRATION EQUIPMENT CONFIGURATION

5. Tune the receiver and spectrum analyzer. Observe that the spectrum analyzer displays two frequencies near 10 MHz, which are exactly the same amplitude and displaced from each other by 1 kHz. The lower frequency signal will represent the desired signal and the higher frequency signal represents an interfering signal. The difference in amplitude between the two signals represents the system signal-to-noise ratio and should always equal the sum of the attenuator settings. If the SNR as indicated by the spectrum analyzer does not agree with the attenuator settings ($\pm$ 1 dB) discontinue testing and determine the cause of the difference.

6. Adjust the attenuator to 3 dB. Adjust R-96 on the measurement module for a reading of 1.10 $\pm$ .02 volts on the digital voltmeter.

7. Adjust the attenuator in 3 dB steps to 21 dB attenuation and record the DVM reading at each step. Monitor the spectrum analyzer during this process to insure that the SNR indicated by the spectrum analyzer is the same as the attenuator reading ($\pm$ 1 dB).

8. Repeat steps 1 through 7 for each SQM module.

9. Compare the readings from all SQM modules, recorded at each attenuator setting. The maximum separation between the highest and lowest reading at each SNR shall be no greater than 0.04 volts. If greater differences are encountered, a subsystem alignment is required.

Time Synchronization of PCM Data

1. Complete steps 1 through 16 of the Playback Site Procedures, 3.1 for proper playback receiver setup.

2. Program all frame synchronizers to accept a pseudo random PCM bit stream (Link BERC or Coded Comm bit error rate test set).

3. Program the bit synchronizers and DSS front panel controls to accomodate the PCM format under test. All testing will be conducted at a bit rate of 350k bits per second. This is necessary to insure that maximum time delays between signal sources do not exceed a maximum of $\pm$ 6 ms.

   NOTE: This test is conducted using only the master and one additional DSS channel due to the nonavailability of test equipment. The test may be conducted, testing all channels, if additional equipment or sites are available.

4. Set up the equipment as shown in Figure 2.

5. Adjust the variable attenuator to 10 dB and adjust the noise output level to produce 1 x 10^{-5} errors.

6. Increase the variable attenuator to 20 dB and verify that the bit error rate (BER) remains at 1 X 10^{-5} errors.

7. Momentarily depress the reset button ON at Coded Comm #1. Verify that the error rate remains at 1 X 10^{-5} during the switching procedure. Repeat this step several times to ensure that the error rate does not change.

8. Decrease the variable attenuator to 0 dB while monitoring the BER. Verify that the BER remains at 1 X 10^{-5} errors.

9. Increase the variable attenuator to 20 dB and press Reset on Coded Comm #1. Repeat steps 8 and 9 several times to ensure that the BER remains at 1 X 10^{-5} errors.

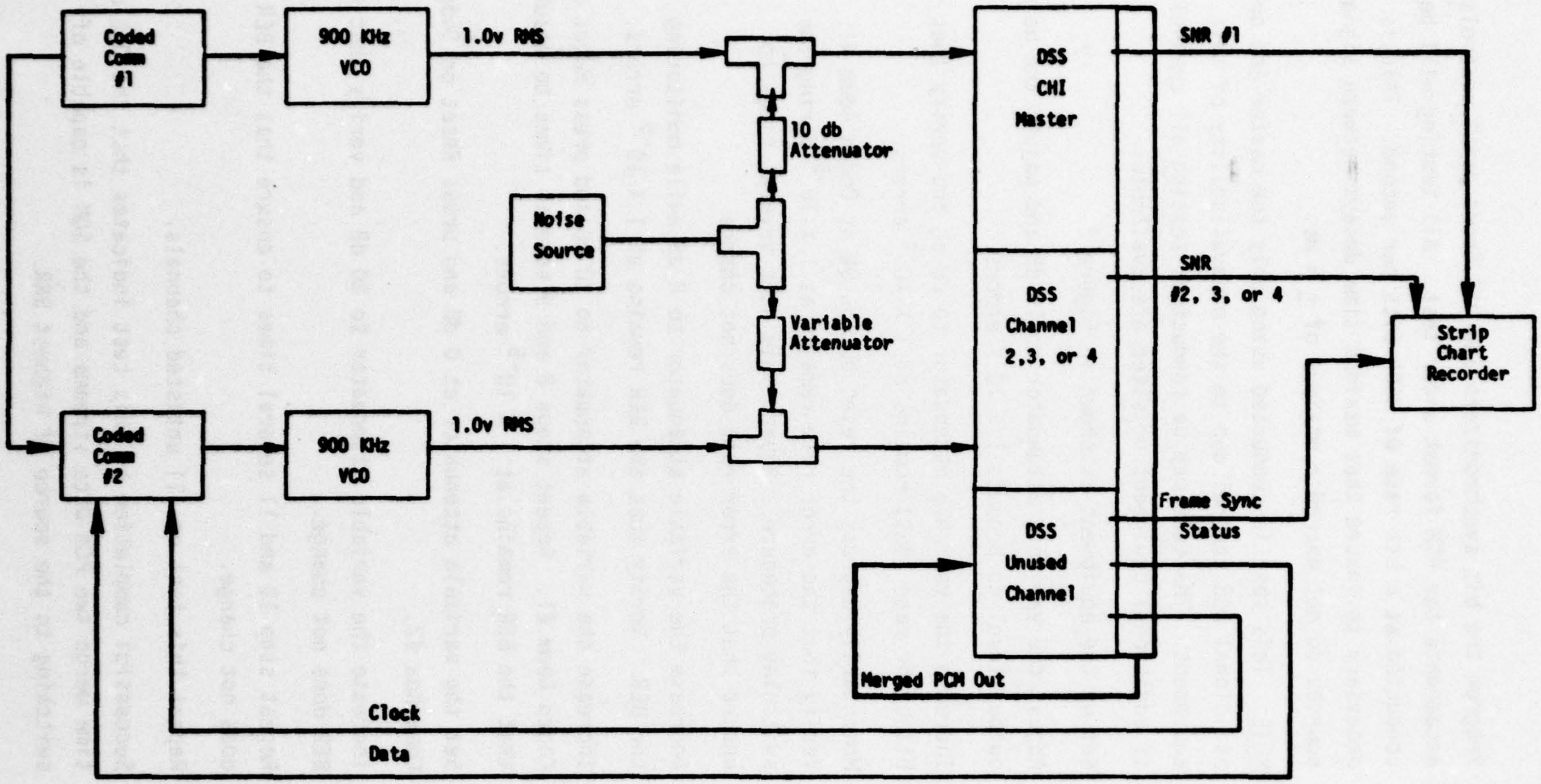
10. Set the variable attenuator at 0 dB and press Reset on Coded Comm Box #2.

11. Increase the variable attenuator to 20 dB and verify that the BER does not change.

12. Repeat step 10 and 11 several times to ensure that the BER does not change.

13. Repeat this test on all untested channels.

14. Successful completion of this test indicates that the DSS can time merge two PCM data streams and the SQM is capable of switching to the source of highest SNR.



CONDITIONS

1. Coded Comm #1 set to internal clock
2. Coded Comm #2 set to external clock - Use clock out of #1 to clock in #2
3. Variable attenuator - HP Mod. 394A or Eq.
4. Unused DSS channel connected for bit sync and frame sync only
5. Output of both VCO's set to 1V RMS (or to the same voltage)
6. Noise source - Marconi noise generator - no filters

FIGURE 2 EQUIPMENT CONFIGURATION, TIME SYNCHRONIZATION

Memory Testing - Conduct testing before launch support and during routine maintenance using the manufacturers supplied memory testing equipment and directions. The testing consists of loading a known pattern into memory then reading the contents of each memory location to insure that the proper read/write functions have been executed. Common patterns may include: all 0's, all 1's alternate 1,0 and alternate 1,0 complement.

SECTION 4
RANGE PLANNING

The theory has been well established for optimum carrier deviation and corresponding receive system bandwidth filters. In addition, the Range Commander's Council has published Document 106-73 revised November 1975, Telemetry Standards, to provide guidelines for equipment compatibility. Unfortunately, many range users do not follow these guidelines. In some cases, the nature of the test requires special or non-standard transmission techniques.

This section is written for two purposes - (1) to promote better understanding between the range and the user by providing the planning models used by the SAMTEC and (2) to provide actual missile data spectrum photographs which are used to update the SAMTEC models.

The theoretical models do not attempt to ensure compliance with the revised Document 106-73. Document 106-73 (revised) describes maximum spectral occupancy while these models describe only the optimum method of transmission. Since the models do employ minimum bandwidth, their use would facilitate compliance with the Telemetry Standards. References include:

1. Report P100-72-38, Red Flag Performance Values for Telemetry Validation Systems, Vandenberg AFB, California: FEC Systems Performance Analysis Directorate, August 7, 1972.
2. IRIG Document 106-73, Telemetry Standards, White Sands Missile Range, Revised November 1975.
3. Report P100-75-18, Telemetry Planning Data, Vandenberg AFB, California: FEC Systems Performance Analysis Directorate, March 20, 1975.

4.1 TRANSMISSION LINK MODELS FOR PCM FORMATS

4.1.1 FM Modulation Theory

Figures 1 through 3 and 5 through 7 are spectrum photographs of an RF signal which has been modulated with a PCM simulator. The spectrum horizontal scale in all cases is calibrated in multiples of the bit rate. On each spectrum is shown the bit rate bandwidth and the optimum RF bandwidth

required to pass the signal with minimum signal degradation. Figures 4 and 8 are spectrum photographs of the post-d PCM which indicate the bit rate bandwidth and the optimum lowpass video filter setting for maximum data recovery. To determine the RF bandwidth necessary for optimum data recovery refer to user information and calculate the deviation ratio (β) where

$$\beta = \frac{\text{(peak carrier deviation)}}{\text{effective square wave rate}}$$

(effective square wave rate = bit rate divided by 2 for NRZ or bit rate for Bi-Ø). The spectrum photo with the corresponding deviation ratio will give the proper bandwidth in terms of bit rate. If the β calculated does not correspond with the β of any photos, interpolate using the following relationship:

$$\text{RF Bandwidth} = x\text{BR} \quad (\text{BR} = \text{Bit Rate})$$

$$x = x_1 - (\beta_1 - \beta) \frac{(x_1 - x_2)}{(\beta_1 - \beta_2)}$$

where β_1 and β_2 are the deviation ratios of the two nearest valued photos and x_1 and x_2 are the corresponding bandwidth constants.

The receiver 2nd IF bandwidth will be equal to the RF bandwidth plus 200 kHz (explained in Section 4.1.2) or the next higher available IF value.

The pre-d bandwidth is equal to 2.4 times the bit rate (BR) for Bi-Ø or 1.2 BR for NRZ, plus 200 kHz for Doppler, mistuning, etc. To find the microwave bandwidth use the pre-D bandwidth value in conjunction with Instruction 1 at the end of Section 4. The required video bandwidth is equal to 0.75 times bit rate for NRZ and 1.25 times bit rate for Bi-Ø. If the value calculated is not available on the receiver, select the next highest value. Figures 1 through 8 are arranged to show the variation in IF bandwidth requirements due to different carrier deviations. The post-d spectrum, however, is constant for all deviations.

Once the quantities are obtained, refer to Simulation Configurations 1, 2 and 3. Choose the appropriate configuration and proceed to validate the system per the attached procedures.

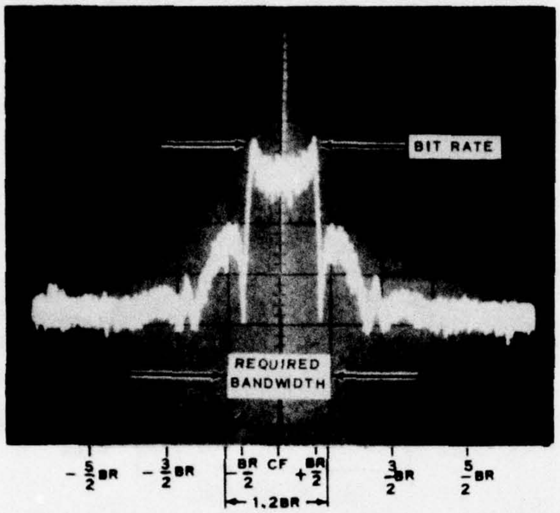


Fig. 1 NRZ PCM/FM
β = .75

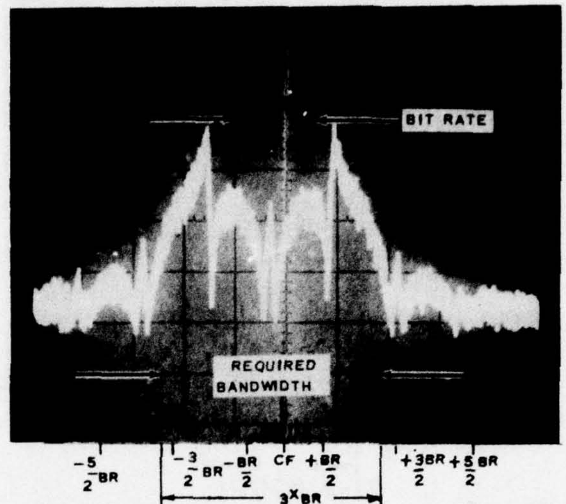


Fig. 3 NRZ PCM/FM
β = 2.0

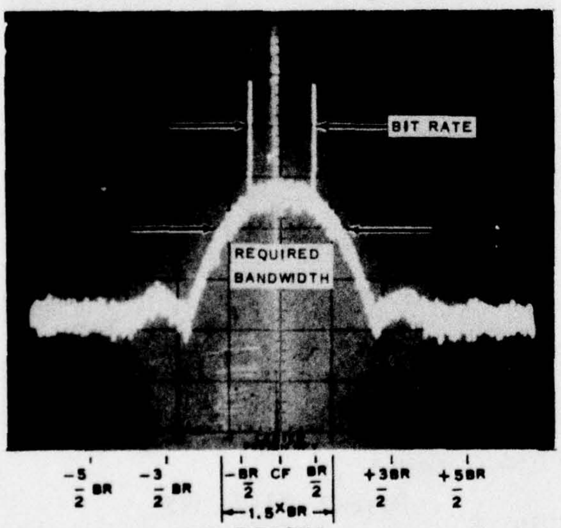
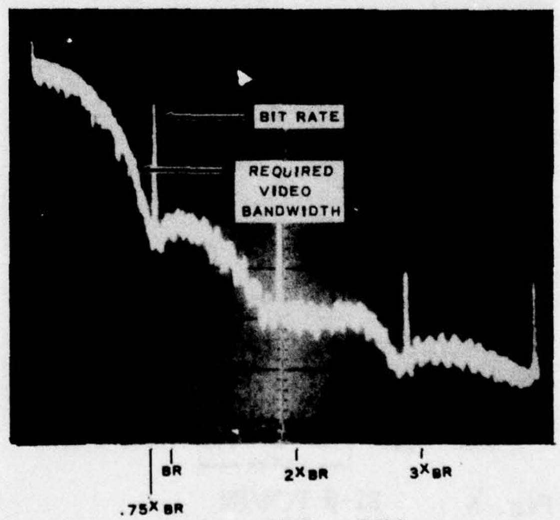


Fig. 2 NRZ PCM/FM
β = 1.0



Post-D NRZ PCM

Fig. 4

Simulation:

See Configuration No. 1

BER Requirements:

1 x 10^{-6} @ 13 db SNR

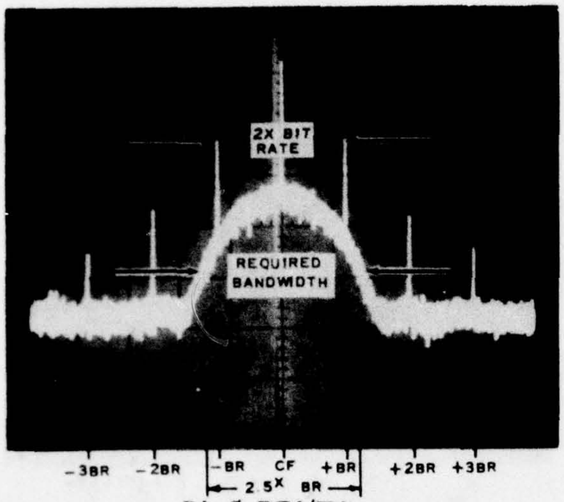


Fig. 5 Bi-Ø PCM/FM

$\beta = .75$

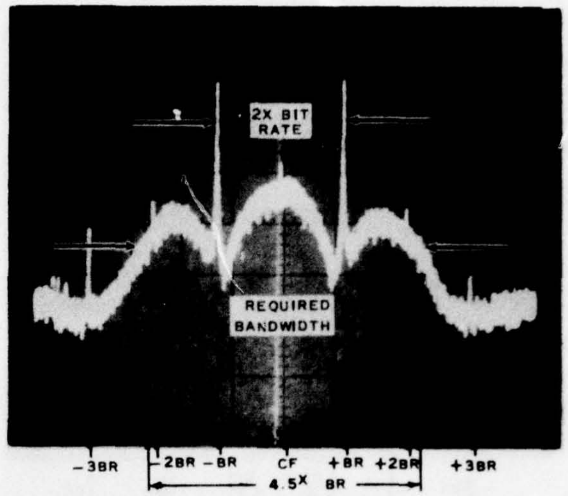


Fig. 7 Bi-Ø PCM/FM

$\beta = 2.0$

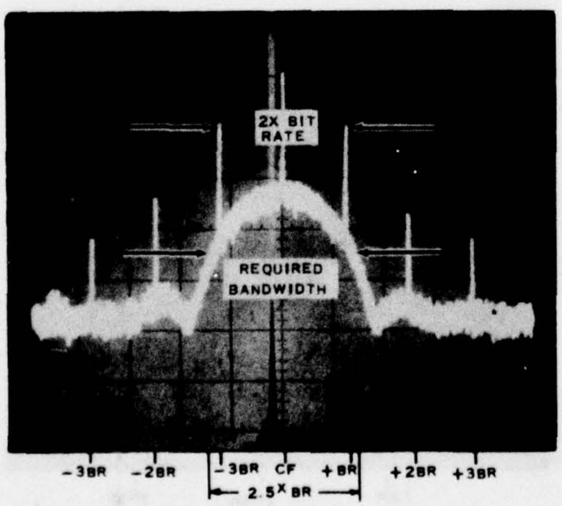


Fig. 6 Bi-Ø PCM/FM

$\beta = 1$

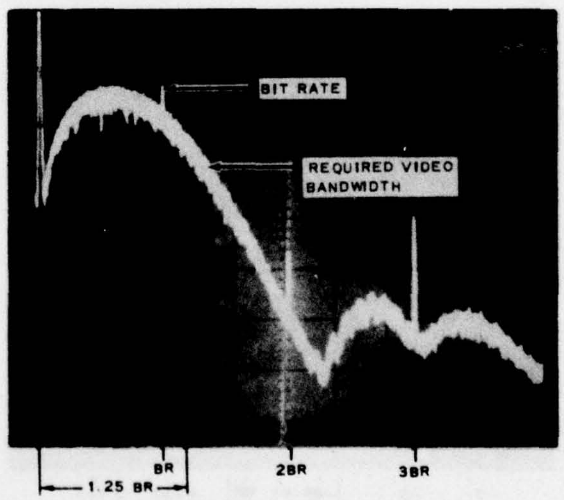


Fig. 8 Post-D Bi-Ø PCM

Simulation:

See Configuration No. 1

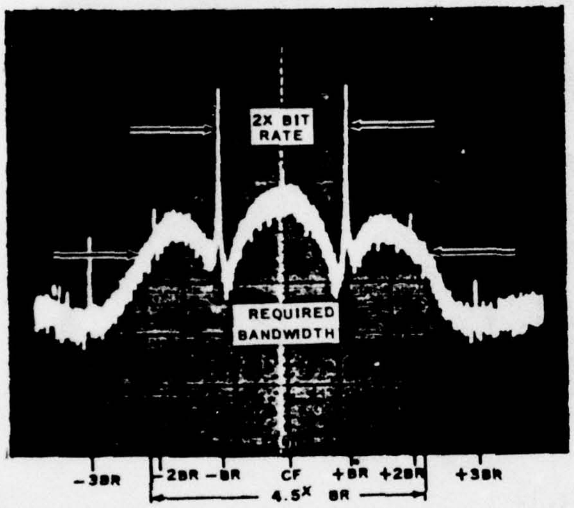
BER Requirements:

1×10^{-6} @ 13 db SNR

Simulation
Configuration No. 1

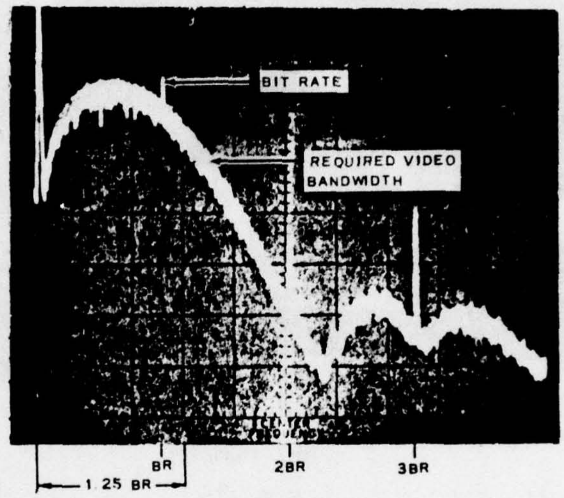
Bi-Ø PCM/FM Simulation and Tape Signature

Deviation Ratio ~ 1.2



Bi-Ø PCM/FM

Fig. 9



Post-D Bi-Ø PCM

Fig. 10

Applic-able OD	Link #	Pre-d	Bit Rate	Peak Deviation	RF Bandwidth	Receiver IF	Video Filter	Microwave Bandwidth
0400	63/88	900 k	29.7/200 kbps	50/250 kHz	900 kHz	1 MHz	250 kHz	1.2 MHz

Equipment Configuration..............................Test Configuration No. 1

Test Procedure......................................Procedure No. 1

Required Acquisition Site Bit Error Rate...........1×10^{-6} at 13 dB SNR

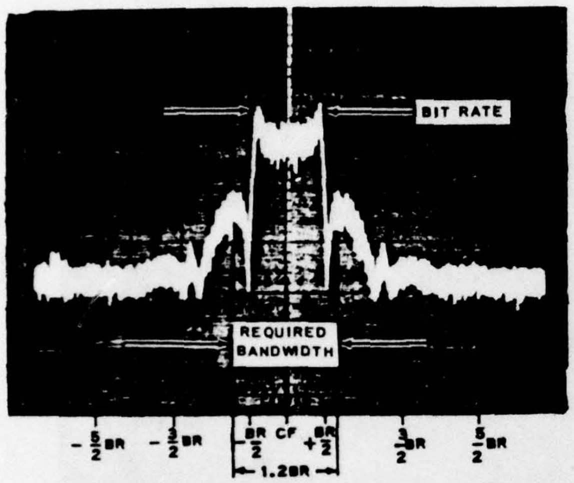
Required Processing Site Bit Error Rate............1×10^{-6} at 14 dB SNR
on Realtime Microwave Relay Data

Testing will be performed at the higher bit rate.

Simulation
Configuration No. 2

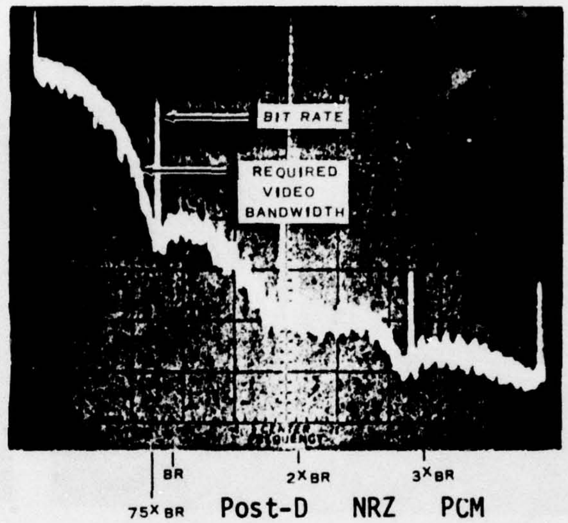
NRZ PCM/FM Simulation and Tape Signature

Deviation Ratio ~ .75



NRZ PCM/FM

Fig. 11 β = .75



Post-D NRZ PCM

Fig. 12

Applic-able OD	RF Link #	Pre-d	Bit Rate	Peak Deviation	RF Bandwidth	Receiver IF	Video Filter Minimum	Microwave Bandwidth
0200	63/88	225 k	40.96 kbps	15.36 kHz	50 kHz	300 kHz	31 kHz	300 kHz
0200	16	900 k	950 kbps	360 kHz	1140 kHz	1500 kHz	750 kHz	1.5 MHz
2500	35	450 k	172.8 kbps	65 kHz	207 kHz	500 kHz	250 kHz	600 kHz
1800	87	900 k	384 kbps	144 kHz	461 kHz	750 kHz	500 kHz	800 kHz
1900	87	900 k	384 kbps	144 kHz	461 kHz	750 kHz	500 kHz	800 kHz
0600	61/88	450 k	308 kbps	108 kHz	370 kHz	750 kHz	250 kHz	N/A

Equipment Configuration............................Test Configuration No. 1

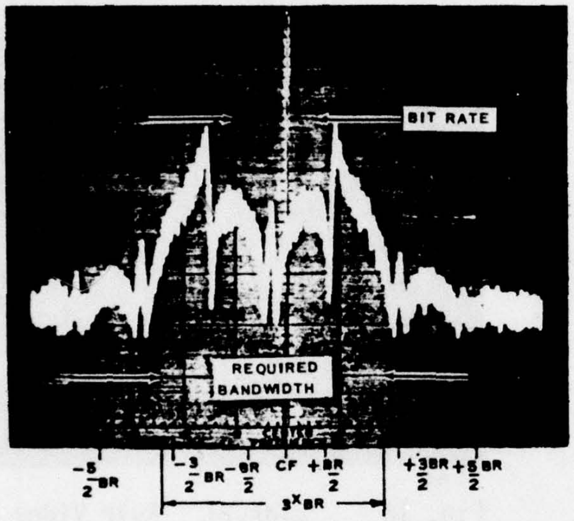
Test Procedure.......................................Procedure No. 1

Required Acquisition Site Bit Error Rate............1×10^{-6} at 13 dB SNR

Required Processing Site Bit Error Rate............1×10^{-6} at 14 dB SNR
Realtime Microwave Relay Data

Simulation
Configuration No. 3

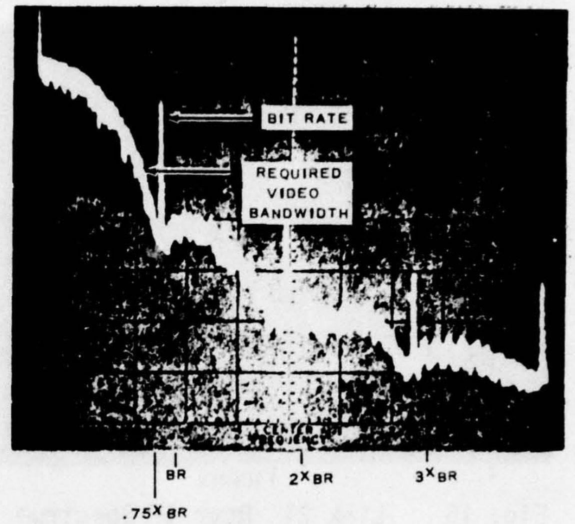
NRZ PCM/FM Simulation and Tape Signature
Deviation Ratio ~ 2.25



NRZ PCM/FM

$\beta = 2.0$

Fig. 13



Post-D NRZ PCM

Fig. 14

Applic-able OD	RF Link #	Pre-D	Bit Rate	Peak Deviation	RF Bandwidth	Receiver IF	Video Filter	Microwave Bandwidth
1700	01/88	450 kHz	131 kbps	150 kHz	430 kHz	750 kHz	100 kHz	600 k

Equipment Configuration............................Test Configuration No. 1

Test Procedure.......................................Procedure No. 1

Required Acquisition Site Bit Error Rate.........1×10^{-6} at 13 dB SNR

Required Processing Site Bit Error Rate..........1×10^{-6} at 14 dB SNR
on Realtime Microwave Relay Data

4.1.2 PM Modulation Theory

Figures 15 and 16 are spectrum photographs of an RF carrier which has been modulated by a PCM simulator. The only PCM/PM format supported by the range has a deviation of approximately 1.6 radians. The bandwidth requirements may be calculated using the information in the FM modulation section.

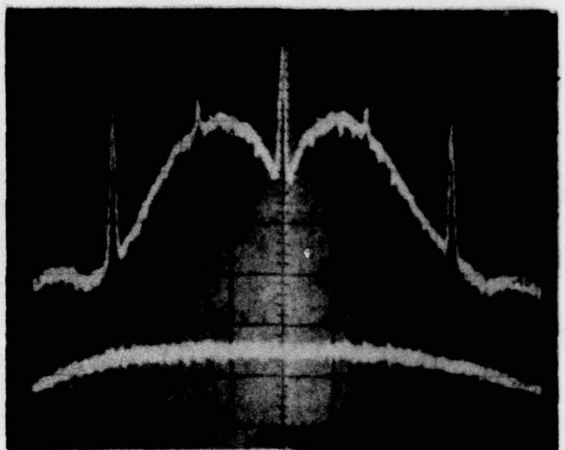


Fig. 15 Link 21 Rcvr IF Spectrum

Top Trace: PCM/PM
Bottom Trace: System Noise with 1.5 MHz IF Filter

-Vertical Scale: 10 db/div
-Horizontal Scale: 200 kHz/div

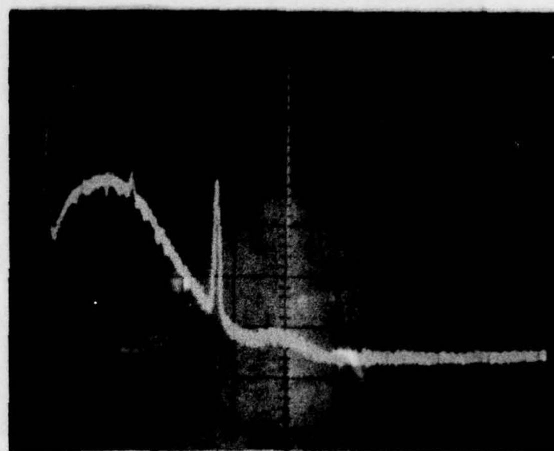


Fig. 16 Link 21 Rcvr Video Output (345.6 Kbs/Bi-Ø-L)

-Vertical Scale: 10 db/div
-Horizontal Scale: 200 kHz/div

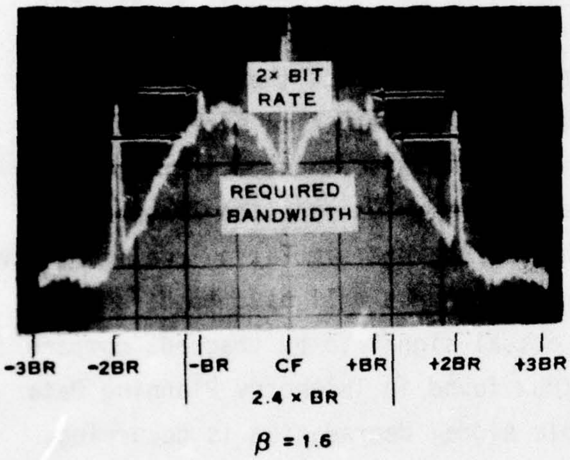
Additional RF Bandwidth Requirements

After determination of the required RF bandwidth to pass a given signal, an additional allowance must be added to compensate for Doppler, receiver tuning errors and transmitter center frequency errors. These errors have been determined to be ± 120 kHz when telemetry receivers are operated in XTAL/XTAL mode. It is therefore necessary to add, to the required bandwidth, an additonal 200 kHz to insure that the required RF spectrum is contained within the receiver IF or microwave pre-d channel bandwidth.

This additional allowance must be employed for PM formats as well as FM formats since FM demodulators are used in the acquisition site receivers for pre-d recording.

Simulation
Configuration No. 4

Bi-Ø PCM/PM Simulation and Tape Signature
Peak Deviation, Rad. ~ 1.6



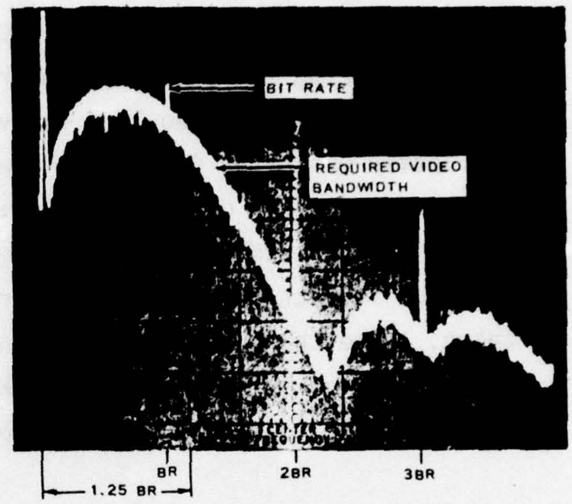


Fig. 17

Bi-Ø PCM/PM

Fig. 18

Post-D Bi-Ø PCM

Applicable OD	RF Link	Pre-D	Bit Rate	Peak Deviation	RF Bandwidth	Receiver IF	Video Filter	Microwave Bandwidth
1000	05	900 k	345.6	1.6 R	825 k	1.5 M	500 K	1.2 M
2389	21	900 k	345.6	1.6 R	825 k	1.5 M	500 K	1.2 M
0400	21	900 k	345.6	1.6 R	825 k	1.5 M	500 K	1.2 M

Equipment Configuration..........................Configuration No. 1

Test Procedure....................................Procedure No. 1

Required Acquisition Site Bit Error Rate..........1 x 10^{-6} at 10 db SNR

Required Processing Site Bit Error Rate...........1 x 10^{-6} at 11 db SNR

4.1.3 Bit Error Rate Test

Assemble the system as shown in Test Configuration No. 19. Obtain the proper equipment settings for the system by calculation or from the OD pertaining to the operation. With the SNR Monitor connected to the receiver IF output, determine the system noise floor (0 db). Then increase the signal generator output to bring the SNR up to the required value and check the BER. Increase the SNR to the value required for validation of the real-time microwave link and notify DC so the BER may be checked there. Connect the spectrum analyzer to the receiver IF output and examine the spectrum. Compare the IF spectrum with the photograph of the spectrum in the appropriate simulation configuration. All requirements must be met or corrective procedures will have to be undertaken. Once the system is receiving the actual signal to be tracked, compare the IF spectrum with an actual link spectrum found in Telemetry Planning Data (Reference 1) to assure that no appreciable signal degradation is occurring.

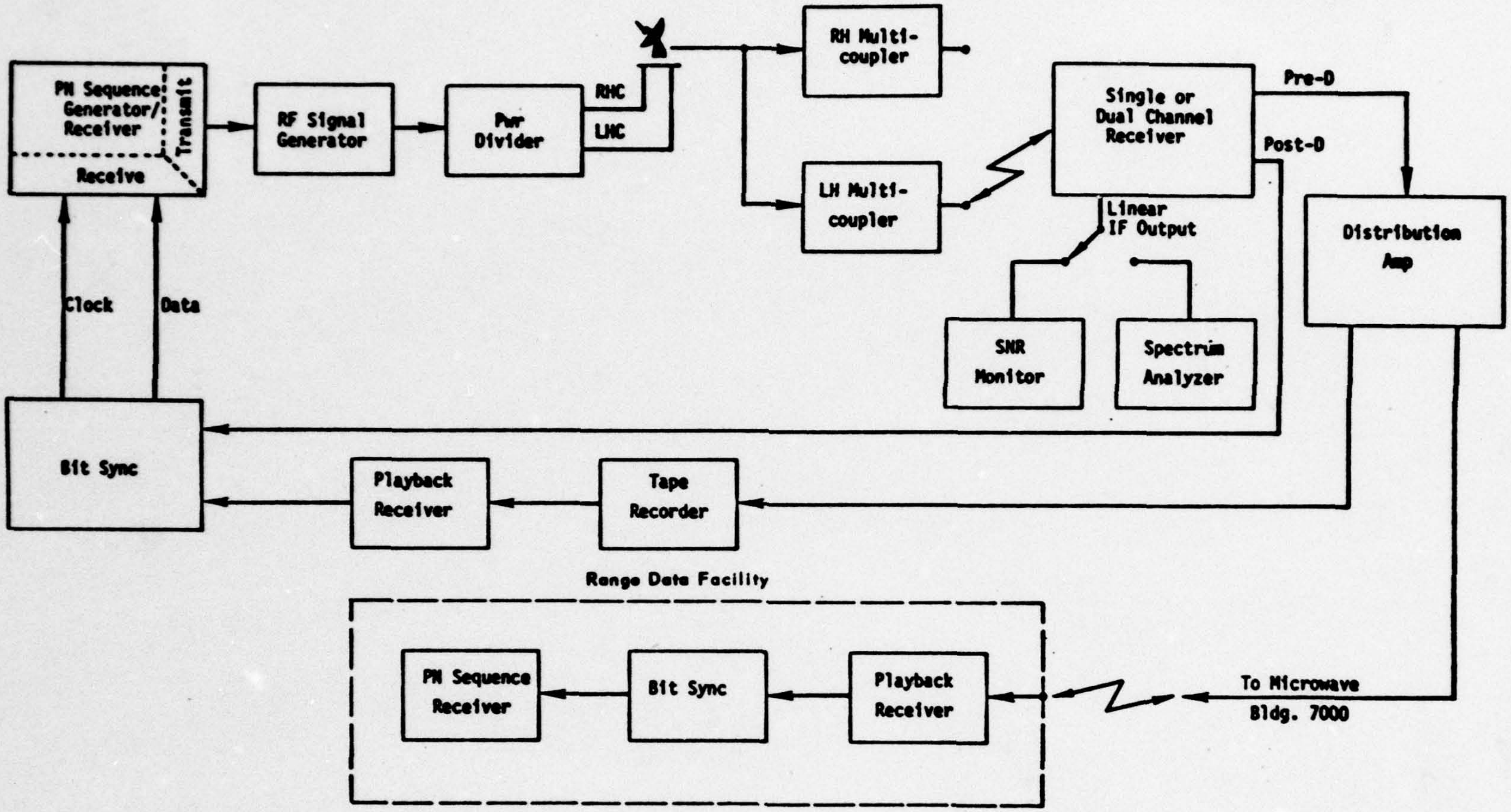


FIGURE 19 BIT ERROR RATE TESTING

4.2 Transmission Link Models for FM/FM and Hybrid Formats

4.2.1 FM/FM Modulation Theory

Predetection Bandwidth The most common form of FM/FM modulation encountered at the WTR consists of a baseband signal which frequency modulates an RF carrier. The baseband signal is composed of several subcarriers each of which is frequency modulated by a specified data signal. The subcarrier frequencies and allowable subcarrier deviations are specified in the IRIG standards and compatible baseband demodulation equipment can be employed for data retrieval. However, the relative amplitudes of the subcarriers and the RF carrier deviation by the baseband is not specified by the IRIG. Consequently, the receiving system predetect bandwidth required for a particular FM/FM link is variable, and the required bandwidth must be determined for each link configuration.

In order to determine the bandwidth required to support an FM/FM link, the relative amplitudes of the subcarriers should be considered. In an FM receiver, the noise power in the video output increases parabolically with frequency. Consequently, it could be expected that a high frequency subcarrier would be greater in amplitude than a lower frequency subcarrier. The actual amplitude relationships, or taper, of the subcarriers depends on the relative signal-to-noise ratio desired on each given subcarrier channel as well as the actual noise response of the receiving and recording system. In general, the "optimum" taper can best be determined through bench testing simulations. Often, however, the specified taper will follow a 1/frequency slope. On occasion, a flat taper will be used. In any event, the taper is generally specified and set by the range user, and it is the support range's task to ensure that the predetect and postdetect bandwidths will accomodate that taper for a given carrier deviation.

In order to determine the predetect bandwidth[1] required, a useful rule of thumb is provided by applying Carson's rule as follows:

$$BW = 2\ (\Delta f_c + f)$$

where

- . BW is the 3 dB predetection bandwidth
- . Δf_c is the peak carrier deviation
- . f is the frequency of the highest subcarrier.

As the highest frequency subcarrier is generally known, it is only necessary to determine the peak carrier deviation in order to estimate the required bandwidth. This can be easily done if the subcarrier deviation schedule is provided, or if the rms or rss[2] carrier deviation is provided with the subcarrier taper. Two examples will illustrate the methods to be employed.

Case 1 — Deviation of the Carrier by Each Individual Subcarrier Specified

Subcarrier kHz	rms or rss carrier deviation from each individual subcarrier
72	45
96	100
165	340

Noting that the peak deviation of the carrier by one subcarrier = rms deviation $\sqrt{2}$; and noting that the peak value of the composite baseband signal is equal to the sum of the peaks values of the subcarriers:

---

(1) It should be noted that the predetect bandwidth is affected by the receiver IF, the down converter data bandwidth, the microwave relay channel, the up converter, the playback receiver, and the recorder. If the bandwidth of one element is significantly narrower than the bandwidths of all other elements, then the narrowest element will determine the effective bandwidth. If the bandwidths of all or several of the elements are approximately equal, then the net result of the cascaded filters will be to significantly reduce the effective bandwidth.

(2) For IRIG baseband conditions, rms (root mean squared) ≈ rss (root sum squared).

$$\Delta f_c = (45 + 100 + 340)\sqrt{2}\ \text{kHz.} \quad = 686\ \text{kHz}$$

$$BW = 2\ (\Delta f + 165)\ \text{kHz.} \quad = 1702\ \text{kHz.}$$

Case 2 Total rms or rss Carrier Deviation Specified

Subcarrier kHz	Normalized subcarrier amplitude volts
72	.45
96	1
165	3.4

rms carrier deviation is 357.25 kHz.

Then let $357.25 \times 10^3 = K\,[(.45)^2 + (1)^2 + (3.4)^2]^{1/2}$

or $K = \dfrac{(357.25 \times 10^3)}{3.5725} =$ 100 kHz per volt

where K is the "deviation sensitivity."

Consequently, the rms carrier deviation due to the 72 kHz subcarrier is (.45) (100) kHz = 45 kHz, the 0.6 kHz subcarrier deviation is 100 kHz, etc. The example is then completed as in Case 1.

Applications of Carson's rule as described above yields comparatively accurate answers for a fully loaded IRIG baseband but will tend to be conservative for partially loaded basebands. In the example given, it could be expected that a 1.5 MHz predetect bandwidth would suffice, as only 3 subcarriers are employed. The planner should be cautious, however, if the bandwidth suggested by the user is significantly lower than the value obtained from Carson's rule.

In some cases, the baseband structure may not be available, and the required bandwidth must be estimated from the rms carrier deviation alone. A "worst case" estimate of peak carrier deviation is obtained if a fully loaded baseband and a flat taper are assumed. In this case, $\Delta f_c \approx 6.5$ (rms carrier deviation). A "best case" estimate is that only a few subcarriers will be

used with a steep taper so that the peak carrier deviation is approximatley the same as the deviation from the highest subcarrier alone. *In this case,* $\Delta f_c \simeq 1.4$ (rms carrier deviation). The most probable estimate is that the baseband will not be fully loaded, and that 1 /frequency taper will be used. Consequently, it would probably be prudent to assume that $\Delta f_c \leq 3$ (rms carrier deviation).

<u>Postdetection Bandwidth</u> - The postdetection bandwidth should be slightly greater than the highest subcarrier frequency plus the peak deviation of that subcarrier. If the peak deviation of the subcarrier is not known, a worst case estimate can be made by noting that the IRIG specifications limit the peak deviation to either 8 kHz or 15% of the subcarrier frequency.

<u>Signal-to-Noise Ratio</u> - In some cases it is useful to estimate the signal-to-noise ratio of a demodulated data signal. The approximate equation is given below.

$$S/N = \frac{\Delta f_{sc}^2 \cdot \Delta f_c^2}{B_{sc}^3 \; f^2} \cdot \left(\frac{S}{N}\right)_{IF} \cdot B_r$$

where

S/N is the signal-to-noise ratio of the data signal

Δf_{sc} is the peak deviation of the subcarrier by the data signal

Δf_c is the peak deviation of the carrier by the subcarrier

B_{sc} is the bandwidth of the subcarrier demodulator. ($B_{sc} \leq 1/2\ B_r$)

f is the frequency of the subcarrier

$(S/N)_{IF}$ is the signal-to-noise ratio in the predetection bandwidth

B_r is the bandwidth of the predetection demodulator.

4.2.2 FM/FM Modulation Test Procedure

Notch Noise Test - Set up the system as shown in Test Configuration No. 2. Choose the noise bandwidth of the noise transmitter as large as possible but don't exceed the minimum video filter value. Select up to three available notch filters spaced evenly within the noise bandwidth.

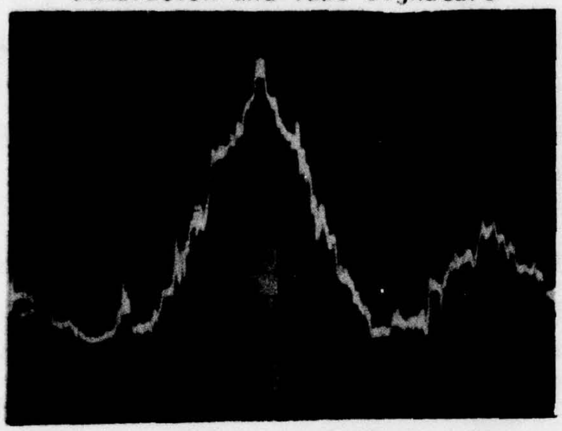
Measure the NPR from both the playback receiver and the system receiver post-d for each of the notch values. Notify RDF when switching filters in and out so the real-time microwave link can be tested. In all cases the NPR should be 30 dB or greater. If not, corrective procedures must be undertaken.

If preferred, a spectrum analyzer can be used in place of the noise receiver. In this case the notches appearing in the spectrum should drop 30 dB or more below the signal power level. When receiving the actual signal to be tracked, the received spectrum may be compared to an actual similar link spectrum photo found in Telemetry Planning Data Handbook (Report PA100-75-18). to assure that no appreciable signal degradation is occurring.

Simulation
Configuration No. 5

PAM/PDM/FM/FM

Simulation and Tape Signature



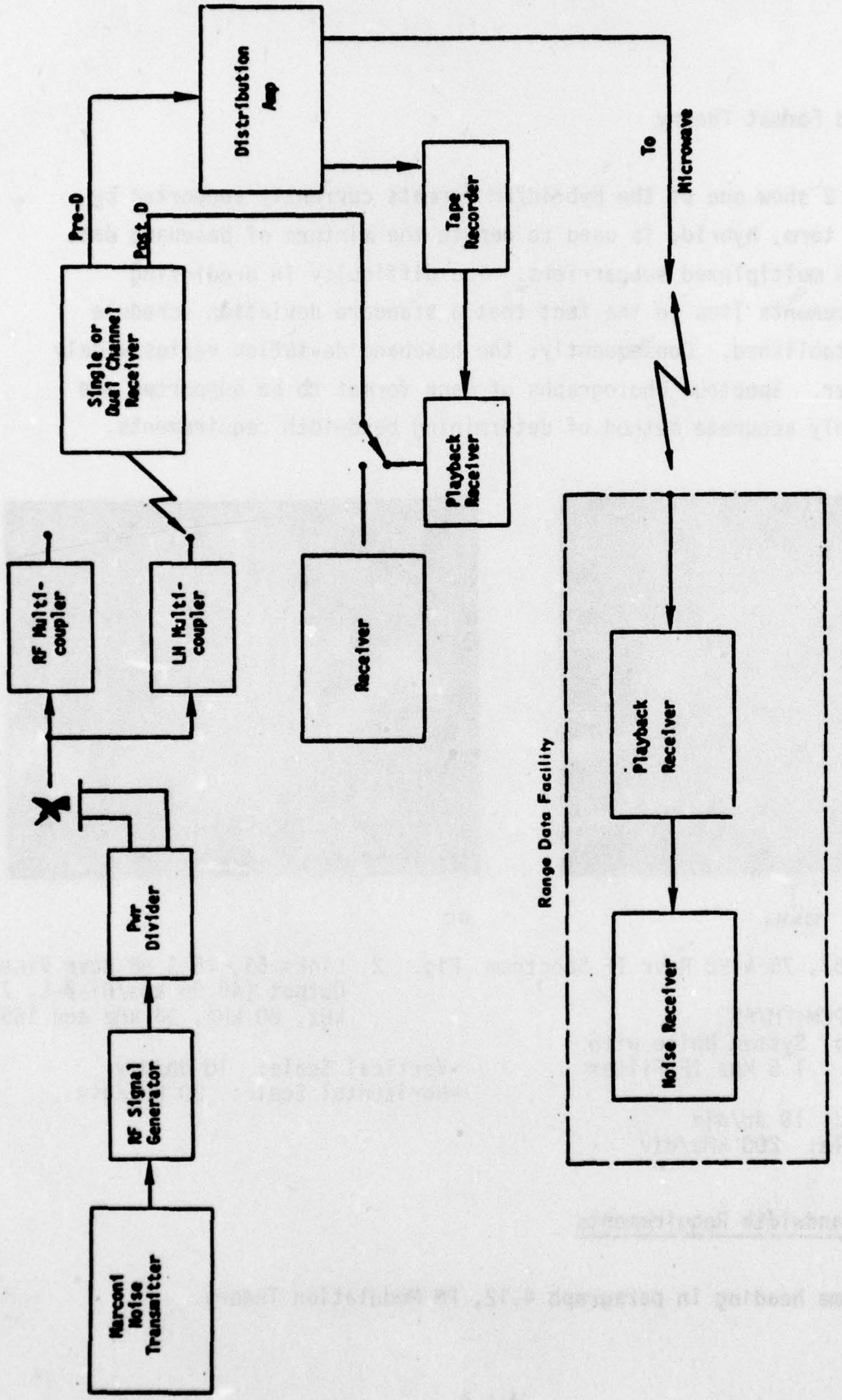
Applicable OD	RF Link	RMS Deviation (kHz)	Noise Bandwidth (kHz)	Notch Filter (kHz)	Receiver IF	Video Filter Minimum	Microwave Bandwidth
0600	43	80	12-204	14,105,185	750 kHz	250 kHz	800 kHz
2800 6500 0200	09 10 43,58	95	12-108	14,34,70	750 kHz	150 kHz	800 kHz
8300 3600	44 30	95	12-108	14,34,70	750 kHz	150 kHz	800 kHz
0700 2389	04,87 63,75,88	210	12-204	14,105,185	1.5 MHz	250 kHz	1.2 MHz
1700	68,06	530	12-204	14,185,534	3.3 MHz	250 kHz	Post-d
3600 0200	400.2 50	25	12-108	14	300 MHz	150 kHz	300 kHz
6500 8300	30 41	125	12-204	14,105,185	1.0 MHz	250 kHz	1.2 MHz
1700	43,58	125	12-204	14,105,185	1.0 MHz	250 kHz	800 kHz
0700	09	80	12-204	14,105,185	750 kHz	250 kHz	600 kHz
3600	68	95	12-108	14,34	750 kHz	150 kHz	800 kHz
5800	1	55	12-108	14,34	500 kHz	150 kHz	600 kHz
0700	50	530	White Nosie of Rcvr IF		3.3 MHz	1.0 MHz	N/A

Equipment Configuration................................Configuration No. 2

Test Procedure...Test Procedure No. 2

Required Acquisition Site Performance..................To be provided

Required Processing Site Performance on Realtime M/W...To be provided



NOTCH NOISE TEST CONFIGURATION NO. 2

4.2.3 Hybrid Format Theory

Figures 1 and 2 show one of the Hybrid/FM formats currently supported by the range. The term, hybrid, is used to denote the mixture of baseband data such as PCM with multiplexed subcarriers. The difficulty in predicting bandwidth requirements lies in the fact that a standard deviation schedule has not been established. Consequently, the baseband deviation varies widely from user to user. Spectrum photographs of each format to be supported are therefore the only accurate method of determining bandwidth requirements.

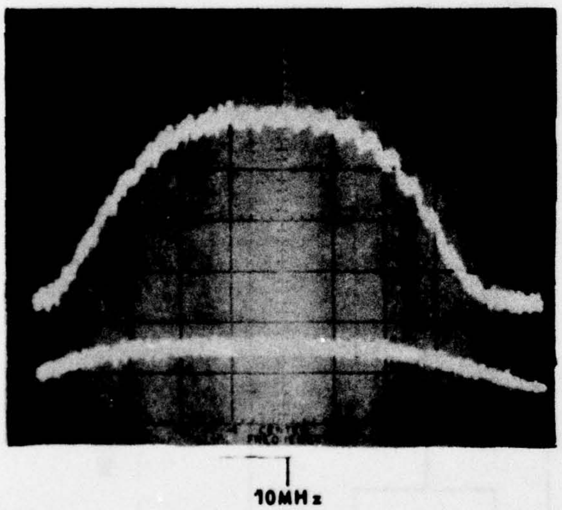


Fig. 1 Links 63, 75 & 88 Rcvr IF Spectrum

Top Trace: PCM+FM/FM
Bottom Trace: System Noise with 1.5 MHz IF Filter

-Vertical Scale: 10 db/div
-Horizontal Scale: 200 kHz/div

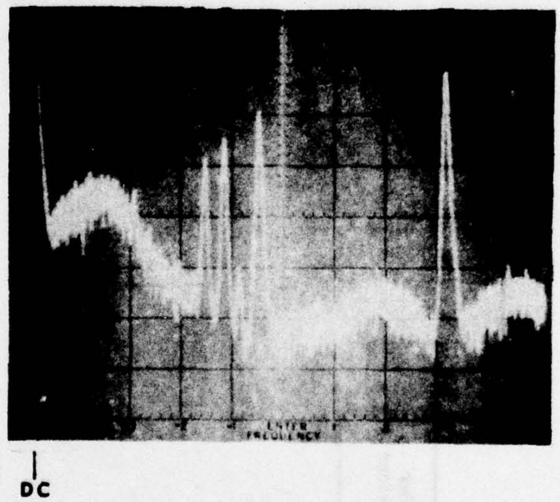


Fig. 2 Links 63, 75 & 88 Rcvr Video Output (40.96 kbs/Bi-Ø-L, 72 kHz, 80 kHz, 96 kHz and 165 kHz)

-Vertical Scale: 10 db/div
-Horizontal Scale: 20 kHz/div

Additional RF Bandwidth Requirements

Refer to the same heading in paragraph 4.12, PM Modulation Theory.

SGLS

Simulation and Tape Signature

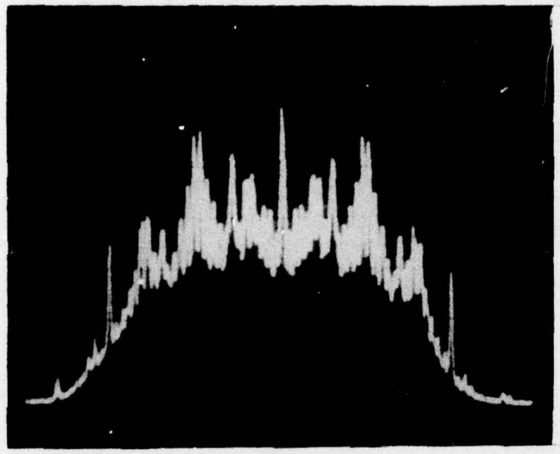


Fig. 3

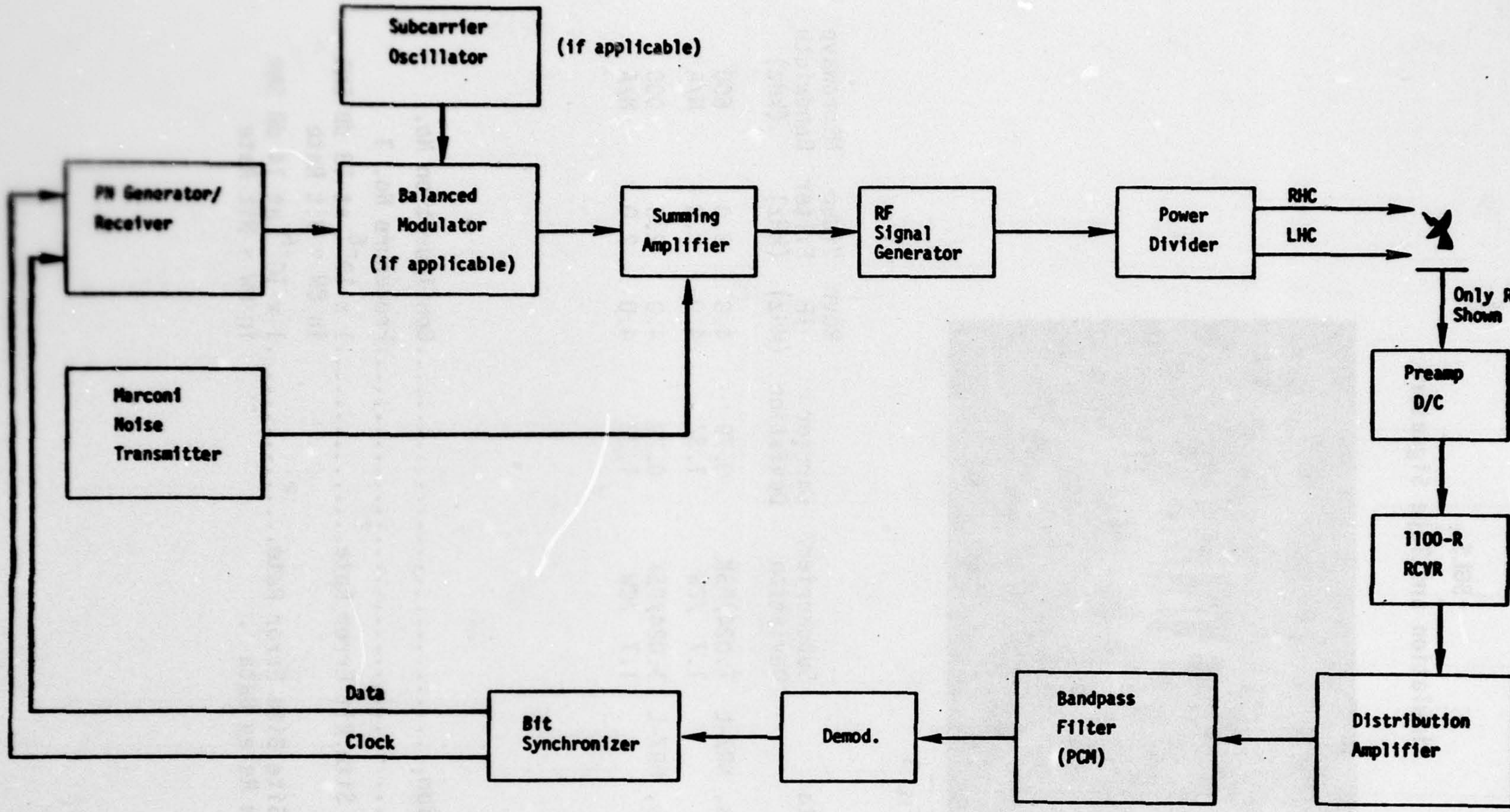
OD	RF Link #	Data	Subcarrier/ Deviation	Carrier Deviation	Rcvr IF (MHz)	Video Filter (kHz)	Microwave Bandwidth (kHz)
1800	22	64 Kbs, NRZ-L	1.024/PSK	0.79	4.0	2.0	600
		None	1.7 /CW	1.32	4.0	2.0	N/A
1900	77	48 Kbs, NRZ-L	1.024/PSK	0.79	4.0	2.0	600
		None	1.7 /CW	1.32	4.0	2.0	N/A

Equipment Configuration..............................Configuration No.

Test Procedure.......................................Procedure No. 3

Required Acquisition Site Bit Error Rate..............1×10^{-6} at 13 dB SNR in BW = Bit Rate

Required Processing Site Bite Error Rate..............1×10^{-6} at 14 dB SNR on Realtime Microwave Relay Data in BW = Bit Rate



EQUIPMENT CONFIGURATION NO. 3

4.2.4 Hybrid Testing

Meaningful system validaton requires that the user provide specifics such as the number of subcarriers and their frequencies, PCM bit rate and deviation ratios. Without this information, system validation will be conducted using an assumed format and serious data degradation may result when supportign the real link.

INSTRUCTION 1

Updated Microwave Information Chart

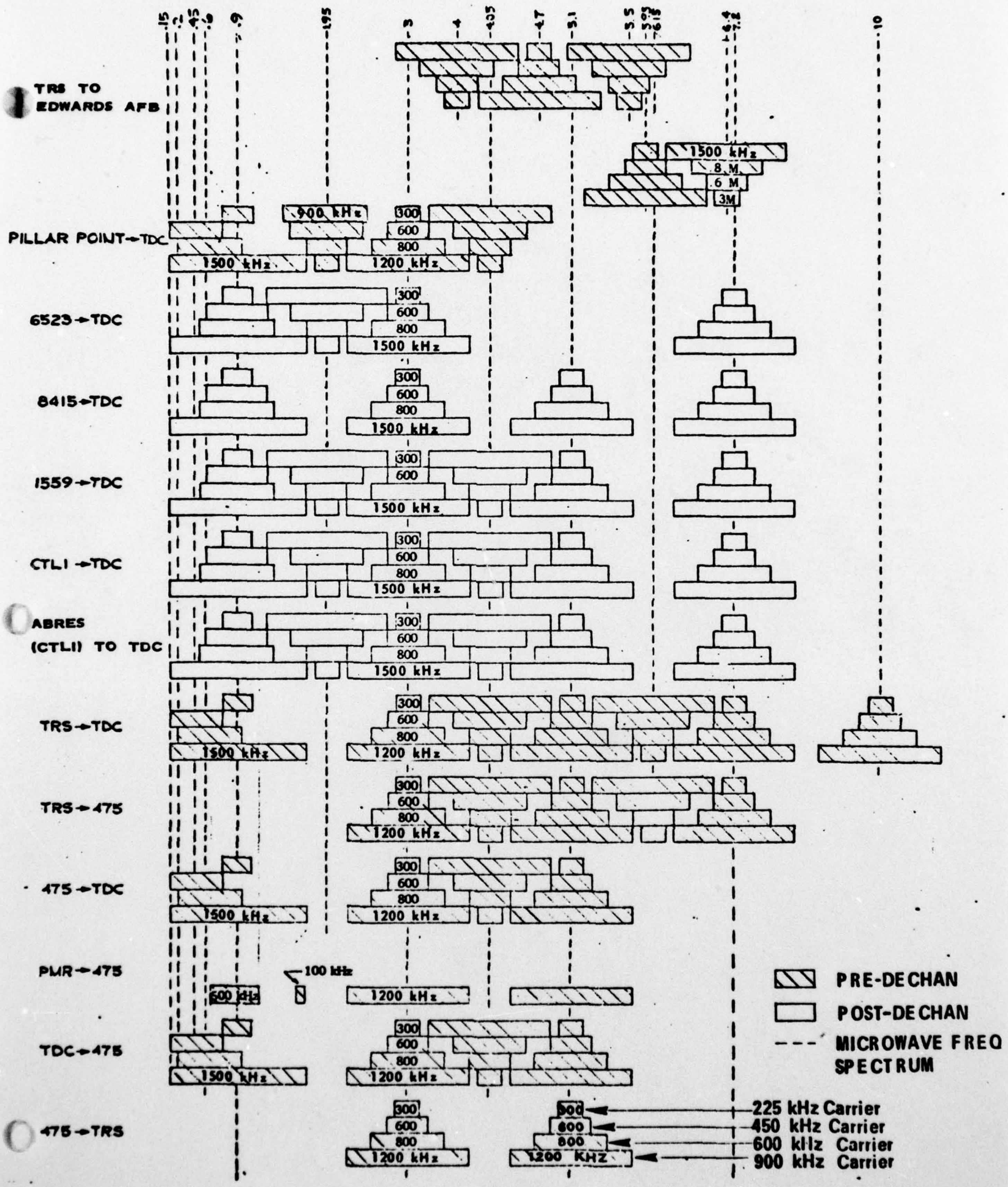
The attached microwave configuration chart reflects the latest information available concerning this systems multiplex channel capability.

Changes on this diagram which should be noted are:

1. All pre-D microwave channels, except the direct channels, have a maximum bandwidth of 1.2 MHz. Direct channel bandwidth is 1.5 MHz.

2. The 1.95 MHz pre-D channel from Pillar Point to Bldg. 7000 has a maximum bandwidth of 900 kHz and should not be used for transmission of Bi-Ø PCM at data bit rates in excess of 350 kbit per second.

Users of this diagram should refer to the section on signal simulation to ensure that assigned microwave channels are of sufficient bandwidth to accomodate the data spectrum. In addition to that bandwidth required by the data, an additional 100 kHz should be included to accomodate the effects of Doppler shift and improper receiver tuning.



MICROWAVE SYSTEM

SECTION 5
TIMING

5.1 TIMING DELAY AND UNCERTAINTIES MEASUREMENT

This procedure defines the method and steps necessary to record the delay and uncertainty of timing pulses, codes, and frequencies decoded from range timing by various data gathering systems. The results of these tests, analyzed and reported, define timing capabilities through individual system terminal detection, development, recording and/or transmission of data. These tests do not include computer processing uncertainties that may occur beyond that point.

Measurements are accomplished by Range Timing Center personnel (Code RC480) as scheduled by OD 6600 (Section 6611). It is the responsibility of individual site personnel to assist the timing center personnel when requested.

The evaluation, analysis and report of the test data are provided by the Performance Analysis Department (PA300) and includes but is not limited to the following for each system measured:

A histogram for each measurement group showing the distribution and population of sample values.

The mean delay plus/minus one Sigma standard deviation calculated and reported for each system. Obvious wild points are ignored.

Each report is identified as to system, location, and date/time of measurements.

5.1.1 Theory

Measurements are taken and recorded once per second. Use of the Moxon 514-116 Precision Timing Divider allows measurements to be taken at faster rates (10, 20, 100 or 1000 pps). All data is referenced to UTC Epoch time and standard frequencies maintained by the timing center in Building 488 and carried to the site with the portable Rubidium Clock. Extended period of runs may be accomplished for up to 24 hours by adjustment of the counter sample rate for one sample every 8 to 10 seconds. Three basic types of measurements will be utilized.

1. Pulse to pulse measurements to identify the point in time where read pulses or digitized time tags occur. This will determine when individual sensor data is taken or tagged so time biases may be applied in data reduction.
2. AC timing measurements to identify when analog timing is applied to recorders in parallel with received data. This will determine when ground stations time tag data so optics, telemetry, and radar information may be compared.
3. Frequency measurements to identify accuracies where frequency is the reference or yardstick, such as the reference frequency in a radar system which establishes the basic unit of distance or slant range.

In reporting time differences between UTC Range Time (portable clock) and the system under test, the U.S. Naval Observatory algebraic method is used. For example: On 14 May 1970, a time comparison performed between the portable clock (PC) and the TPQ-18 time code translator (TCT) indicated that the translator time lags, or occurs 99 microseconds after the portable clock. This should be reported as follows:

PC - TCT = 99 microseconds
(TPQ-18, 14 May 1970)

This means that if a time interval counter had been started by the one pulse per second output of the portable clock and stopped by the one pulse per second output of the translator, the reading displayed on the time interval counter would have been 99 microseconds.

However, if the time interval counter had been started by the one pulse per second output of the translator and stopped by the one pulse per second output of the portable clock, the reading displayed on the time interval counter would have been 999901 microseconds. This reading is equivalent to the negative number (-99 microseconds) because the counter could not be stopped by the corresponding second pulse of the portable clock, but only by the following second pulse. Therefore, one (1) second has to be subtracted from the reading and would have been recorded as follows:

TCT - PC = -99 microseconds
(TPQ-18, 14 May 1970)

The above notation must be modified to include test method and equipment uncertainties plus jitter or variation of the mesured signal and as an example, would be shown as follows:

PC - TPQ-17 (14 May 1970) = 99* plus/minus 12 microseconds**

* Mean delay of measured event with respect to Vandenberg Timing Operations Center time carried by the portable clock.

** Total test uncertainties plus one sigma (standard deviation) of the event measured.

5.1.2 Test Procedures

The following test equipment is in the custody of the Range Timing center, and these or acceptable substitutes will be used for all measurements. Specifications are listed for information to be used in development of test accuracy and uncertainty figures.

	MODEL	DESCRIPTION	MFR.
1.	5065A	Rubidium Frequency Standard Standard Outputs: 5 MHz, 1 MHz, 1 vrms 50 ohm 1 pps, +5V Min. 1k ohm, rise time less than 50 µs Long term stability: $\pm 1 \times 10^{-11}$/month	HP
2.	5248M	Electronic Counter	H P
	5267A	Time Interval Unit Combined specifications: Accuracy (pulse-to-pulse measurements) $\pm$1 period $\pm$Time Base Accuracy	H P

NOTE: Stop pulse rise time and stop trigger level should be considered in evaluation of accuracy and uncertainty

RESOLUTION: 10 nsec to 1 sec depending on standard frequency counted (100 MHz to 1 Hz)

3.	514-116	Precision Timing Divider Specifications: Inputs Time Base: 5 or 1 MHz at 1 vrms into 1 kohm Sync: 1 pps at +10 volts into 50 ohms PRR: 1000,100,20,10 and (2) 1 pps Ampl: +3 volts min into 1 kohm Rise Time: 50 nanoseconds Timing: On time -0 to 0.5 microseconds	Moxon
4.	180A	Oscilloscope Sweep Magnifier, x5 and x10 accuracy ±5 percent	H P
	1801A	Dual Channel Vertical Amplifier Plug-In	H P
	1821A	Time Base Plug-In Main time base, 0.1 microsecond/div. to 1s/div ±3 percent with vernier in calibrated position.	H P
5.	5050B	Digital Recorder Accuracy: Identical to time interval	H P

Column Identification:

	10	9	8	7	6	5	4	3	2	1	
Paper	1	5					1	7	1	2	Line 5 (stop)
Travel	1	5					1	7	0	9	Line 4
	1	5					1	7	1	0	Line 3
	1	5					1	7	1	4	Line 2
	1	5					1	7	0	9	Line 1 (Start)

Columns 1 thru 8: Data

NOTE: One significant zeroes are printed.

Column 9: "5" denotes microseconds
"4" denotes milliseconds
"3" denotes seconds
"2" denotes kHz
"1" denotes MHz

Column 10: "1" denotes 1 decimal place.
"2" denotes 2 decimal places, etc.

Four test setups provide the required measurements.

Test Setup No. 1

Procedures for test setup No. 1 are divided between the steps required for precalibration and the steps required for postcalibration.

Precalibration

A test for precalibration record of time difference between the portable clock and the Range Timing Center is performed after portable clock synchronization and before departure for remote site measurements.

1. Set up the test equipment as shown in Figure No. 1.
2. Counter Switch Positions:

"Sample Rate" set for 1 pps gate rate
"Time Base" to 0.1 microsecond
"Function" to Remote or Time Interval
"Sensitivity" to Plug-In

3. Time Interval Switch Positions:

Start Channel

"Atten" to X1
"ac-dc" to dc
"Slope" to +
"Level" to +2

Stop Channel

"Slope" to +
"ac-dc" to dc
"Atten" to X1
"Level" to +2
"Sep-Com" to Sep

4. Momentarily connect Range Timing (+) to 1 pps to Portable Clock "Sync".
5. Connect Range Timing (+) 1 pps to Time Interval Start Channel input.

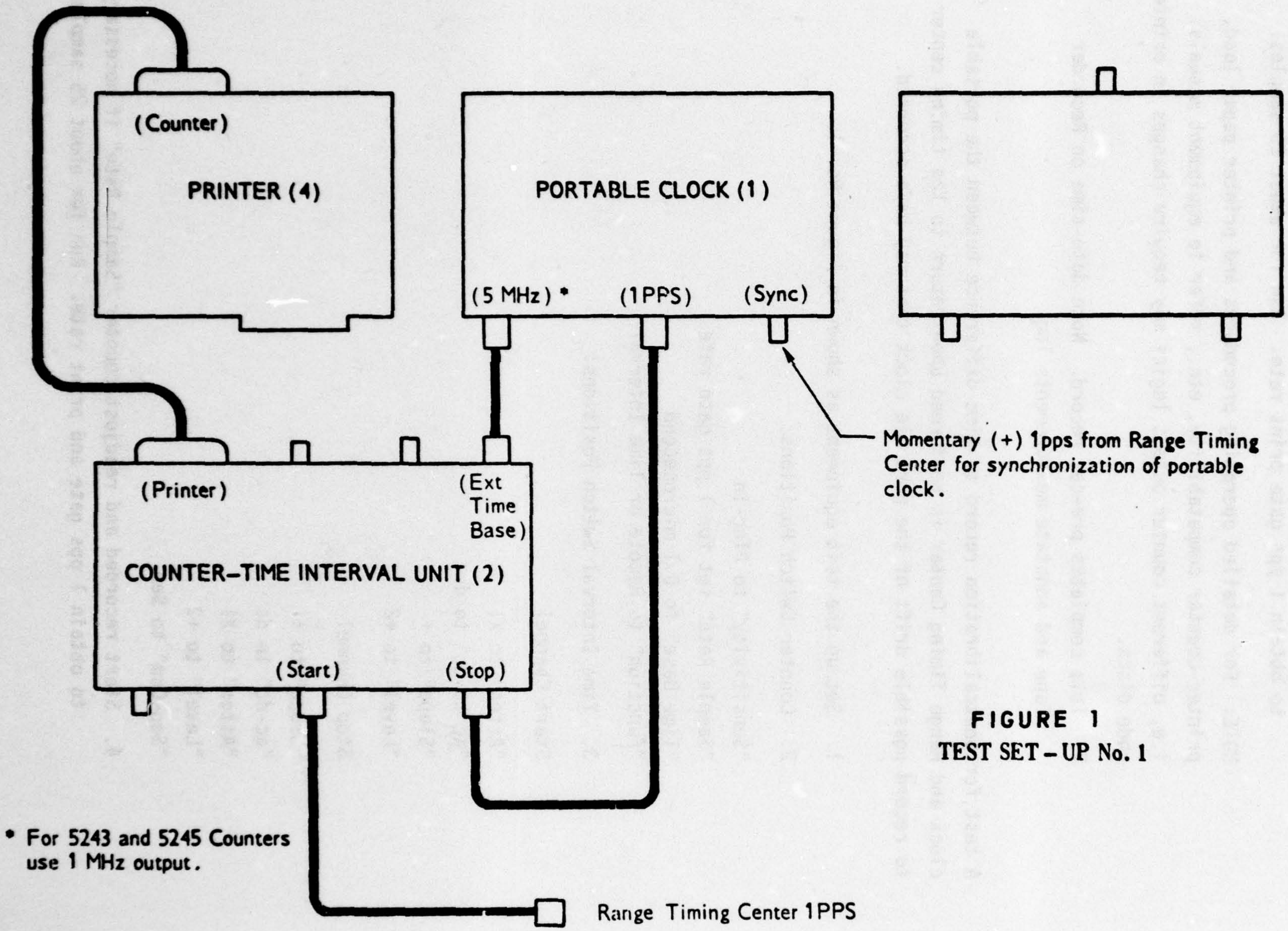


FIGURE 1
TEST SET – UP No. 1

6. Start recorder and readjust counter "Sample Rate" if necessary to obtain 1 pps gate print rate. Run for about 25 samples.

NOTE: For detailed operating procedures and printer paper load, printer-counter compatability, etc., refer to equipment manuals; i.e, different counter output logics may require changes in printer code discs.

7. This completes pre-cal record. Note date-time on Recorder Tape and annotate measurements log.

A test for postcalibration record to time difference between the portable clock and Range Timing Center is performed upon return to the timing center to record possible drift of the portable clock that may have occurred.

1. Set up the test equipment as shown in Figure No. 1.

2. Counter Switch Positions:

"Sensitivity" to Plug-In
"Sample Rate" set for 1 pps gate rate
"Time Base" to 0.1 microsecond
"Function" to Remote or Time Interval

3. Time Interval Switch Positions:

Start Channel

"Atten" to X1
"ac to dc" to dc
"Slope" to +
"Level" to +2

Stop Channel

"Slope" to +
"ac-dc" to dc
"Atten" to X1
"Level" to +2
"Sep-Com" to Sep

4. Start recorded and readjust counter "Sample Rate" if necessary to obtain 1 pps gate and print rate. Run for about 25 samples.

5. This completes post-cal records. Note date-time recorder tape and annotate measurements log.

Test Setup No. 2

This test configuration provides for time delay measurements or pulse-to-pulse comparisons of dc signals with fast rise times (approximately one microsecond or less).

1. Set up the test equipment as shown in Figure No. 2.

2. Oscilloscope Switch Positions:

Vertical Amplifier

"Display" to A
"A Position" center as necessary
"Polarity" to + UP
"Volts" scale as necessary
"ac-dc" to dc

Time Base

"Time/Div" scale as necessary
"Sweep Mode" to Norm
"Ext-Int" to EXT
"Slope" to +
"ac-dc" to dc
"Trigger Level" set for reliable trigger
"Vernier" to cal

3. Note amplitude of pulse to be measured then set Stop Channel Attenuation.

4. Connect Tee to Time Interval Unit.

5. Counter Switch Positions:

"Sample Rate" set for 1 pps gate rate
"Time Base" to 0.01 microsecond
"Function" to Time Interval
"Sensitivity" to Plug-In

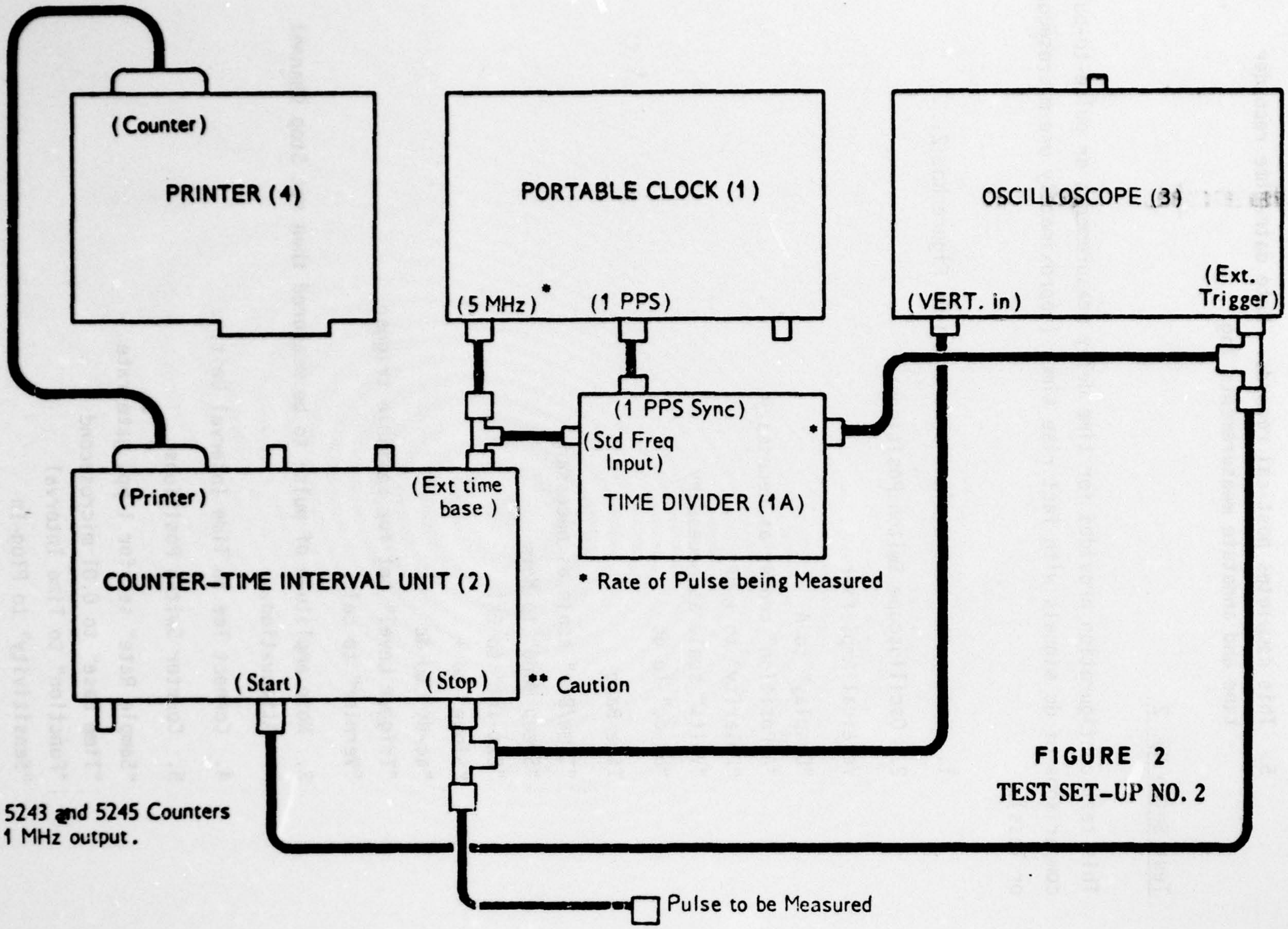


FIGURE 2
TEST SET-UP NO. 2

* For 5243 and 5245 Counters use 1 MHz output.

** Do not connect Tee to TIU until proper attenuation level has been determined based upon pulse amplitude observed on oscilloscope.

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TELEMETRY SYSTEMS CALIBRATION AND VALIDATION HANDBOOK.(U)

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UNCLASSIFIED PA100-77-40 SAMTEC-TR-78-56 NL

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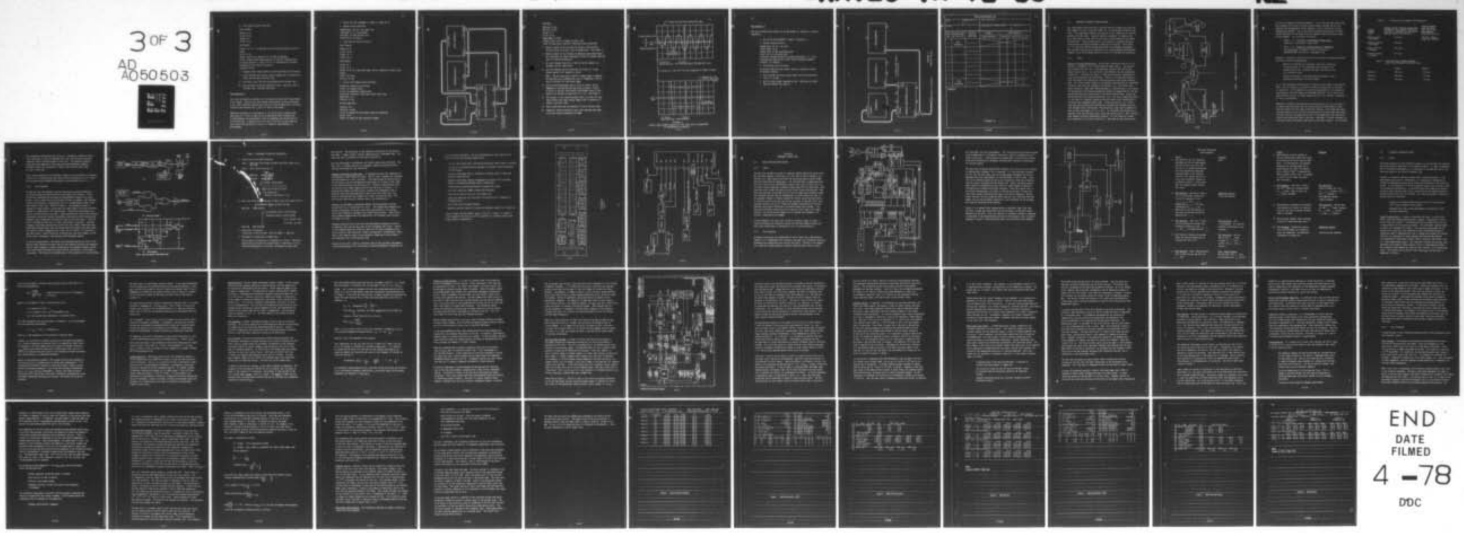

END

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DDC

6. Time Interval Switch Positions:

Start Channel

"Atten" to X1

"ac-dc" to dc

"Slope" to +

"Level" to +2

Stop Channel

"Slope" to + or - as required by pulse polarity noted on oscilloscope.

"ac-dc" to dc

"atten" position as required for reliable triggering.

"Level" preset may be used, however, if noise or ringing exists on signal baseline, a level of 2 or 3 is desirable for reliable triggering up the slope of the pulse.

"Sep-Com" to Sep

7. Compare counter delay reading vs that observed on oscilloscope.

8. Start recorder and readjust counter sample rate if necessary to obtain desired gate and print rate.

9. Note date, start time and system measured on recorder tape.

10. Run recording for period required by user. Note stop time in recorder tape. Annotate log sheet.

Test Setup No. 3

This test configuration provides for timing delay or phase shift measurements of ac signals. Applying the stop channel output marker to the oscilloscope Z axis input (intensity modulation) allows for precise detection of zero-axis crossover and determine the T_o point of IRIG ac time codes.

Measuring the delay of a time code on a 1 kc carrier with a peak-to-peak amplitude of 2.2 volts (0 dBm) can be accomplished within uncertainties of approximately one microsecond or less by expanding the vertical gain to 10 millivolts/cm. A deviation of 0.01 volts (1cm) from the zero baseline only shifts the stop pulse in time by 0.5 degree or approximately 1.5 microseconds.

1. Set up the test equipment as shown in Figure No. 3.

2. Counter Switch Positions:

"Sample Rate" set for 1 pps gate rate
"Time Base" to 0.1 microsecond
"Function" to Time Interval Unit
"Sensitivity" to Plug-In

3. Time Interval Switch Positions:

Start Channel

"Atten" to X1
"ac-dc" to dc
"Slope" to +
"Level" to +2

Stop Channel

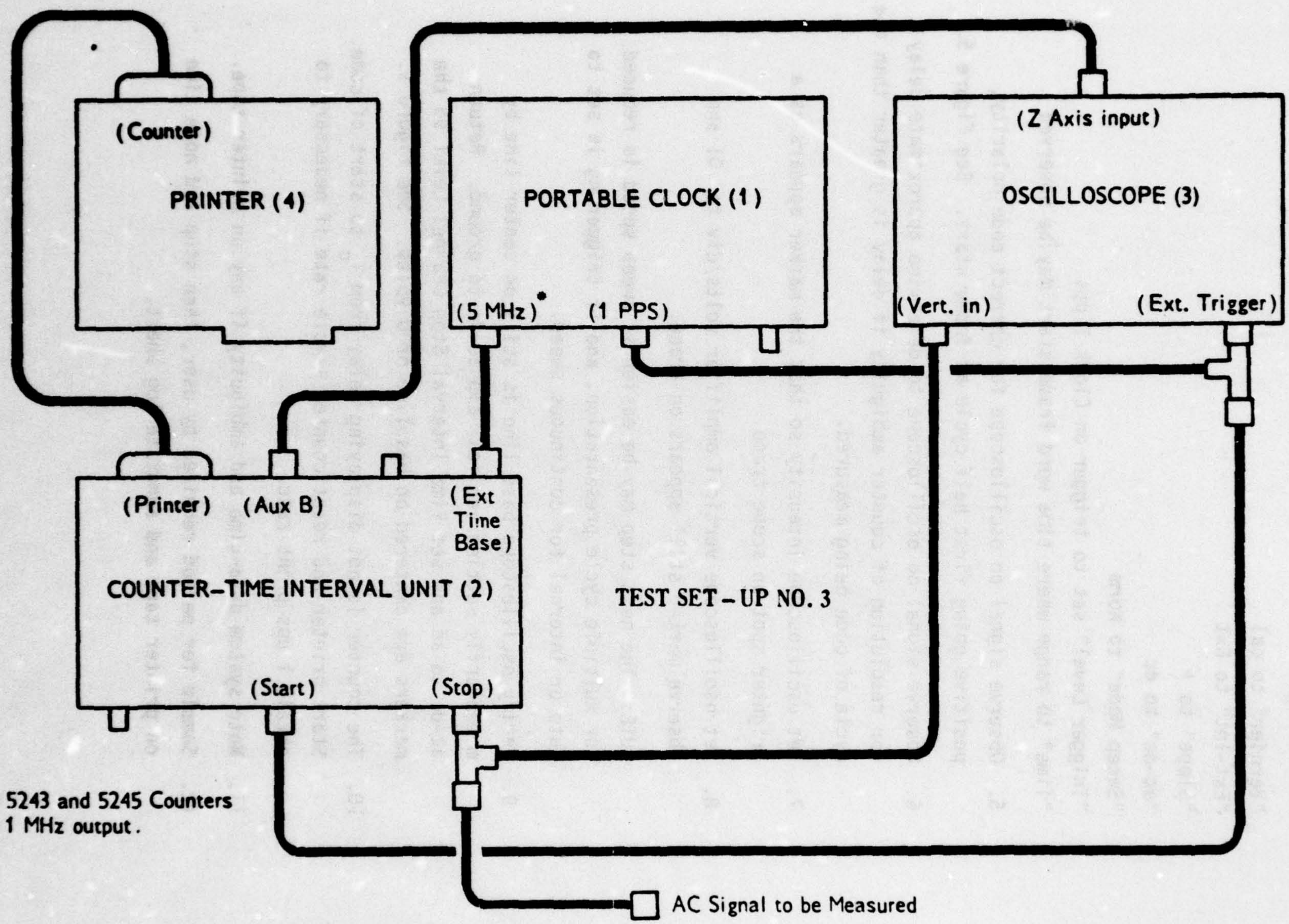
"Slope" to +
"ac-dc" to ac
"Atten" to X1 for 0 dbm IRIG codes; set as required for other level signals.
"Level" to Preset
"Sep-Com" to Sep

4. Initial oscillogram switch positions.

"Intensity" reduce to a low level
"Focus" to sharpest trace
"Scale" to acceptable viewing level
"Horizontal Positions" trace start level scale line
"Magnifier" to X1
"Display" to Int.

Vertical Amplifier

"Display" to A
"Polarity" to +Up
"ac-dc" to ground for positioning trace to centerline
"ac-dc" to ac
"Volts" to range for easy viewing of signal



* For 5243 and 5245 Counters use 1 MHz output.

FIGURE 3

Time Base

"Vernier" to cal

"Ext-Int" to Ext

"Slope" to +

"ac-dc" to dc

"Sweep Mode" to Norm

"Trigger Level" set to trigger on Clock 1 pps

"Time" to range where time word frame start may be observed

5. Observe signal on oscilloscope for correct code polarity, positive going first half cycle at frame start. See Figure 5.

6. Observe signal on oscilloscope to determine approximate delay for resolution of counter ambiguity if delay is greater than one cycle of code being measured.

7. Set oscilloscope intensity so that the marker appears as a brighter spot on scope trace.

8. Set oscilloscope vertical amplifier volts/div to .01 and observe marker still appears on trace.

   NOTE: The next step may be easier if sweep speed is reduced for multiple cycle presentation, and if triggering is set to auto or internal for continuous sweep.

9. Verify oscilloscope base line is still on center line by momentarily setting vertical amp ac-dc to ground. Return ac-dc to ac and set Time Interval Stop Channel Level so the markers are centered on baseline or 0 volts. See Figure 5.

10. The counter is not displaying delay from T_0 to start of code. Start printer and reset counter sample rate if necessary to obtain 1 pps print rate.

11. Note system data-time and ambiguity if any on printer tape.

12. Sample for period required by user, then stop and note time on printer tape and annotate log sheet.

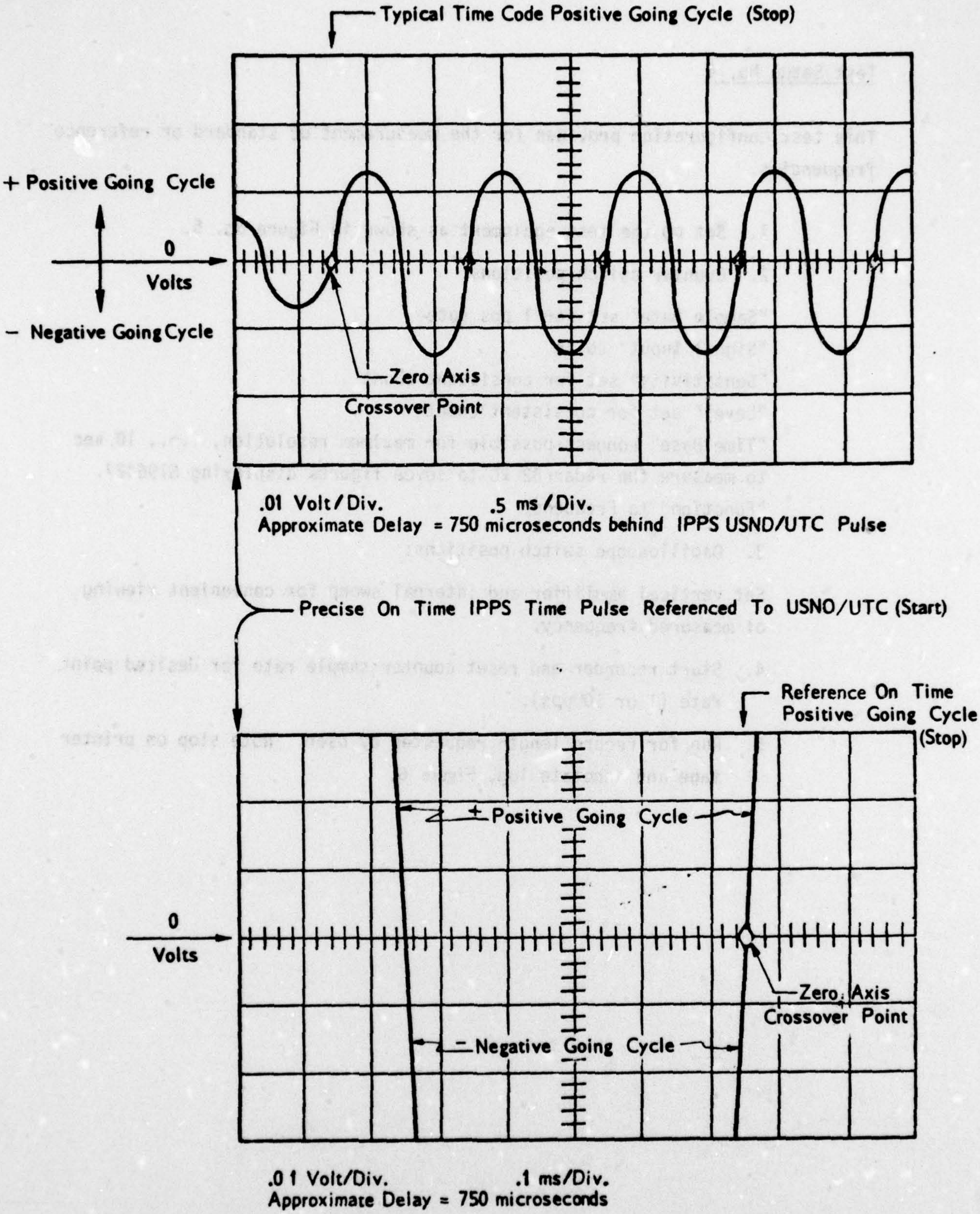


FIGURE 4

TYPICAL OSCILLOSCOPE DISPLAY OF TIME CODE DELAY MEASUREMENT AS REFERENCED TO USND/UTC

Test Setup No. 4

This test configuration provides for the measurement of standard or reference frequencies.

1. Set up the test equipment as shown in Figure No. 5.
2. Counter switch positions:

"Sample Rate" set for 1 pps gate
"Signal Input" to ac
"Sensitivity" set for consistent count
"Level" set for consistent count
"Time Base" Longest possible for maximum resolution, i.e., 10 sec to measure the radar 82 kC to seven figures displaying 8196427.
"Function" to Frequency

3. Oscilloscope switch positions:

Set vertical amplifier and internal sweep for convenient viewing of measured frequency.

4. Start recorder and reset counter sample rate for desired point rate (1 or 10 pps).
5. Run for record length requested by user. Note stop on printer tape and annotate log, Figure 6.

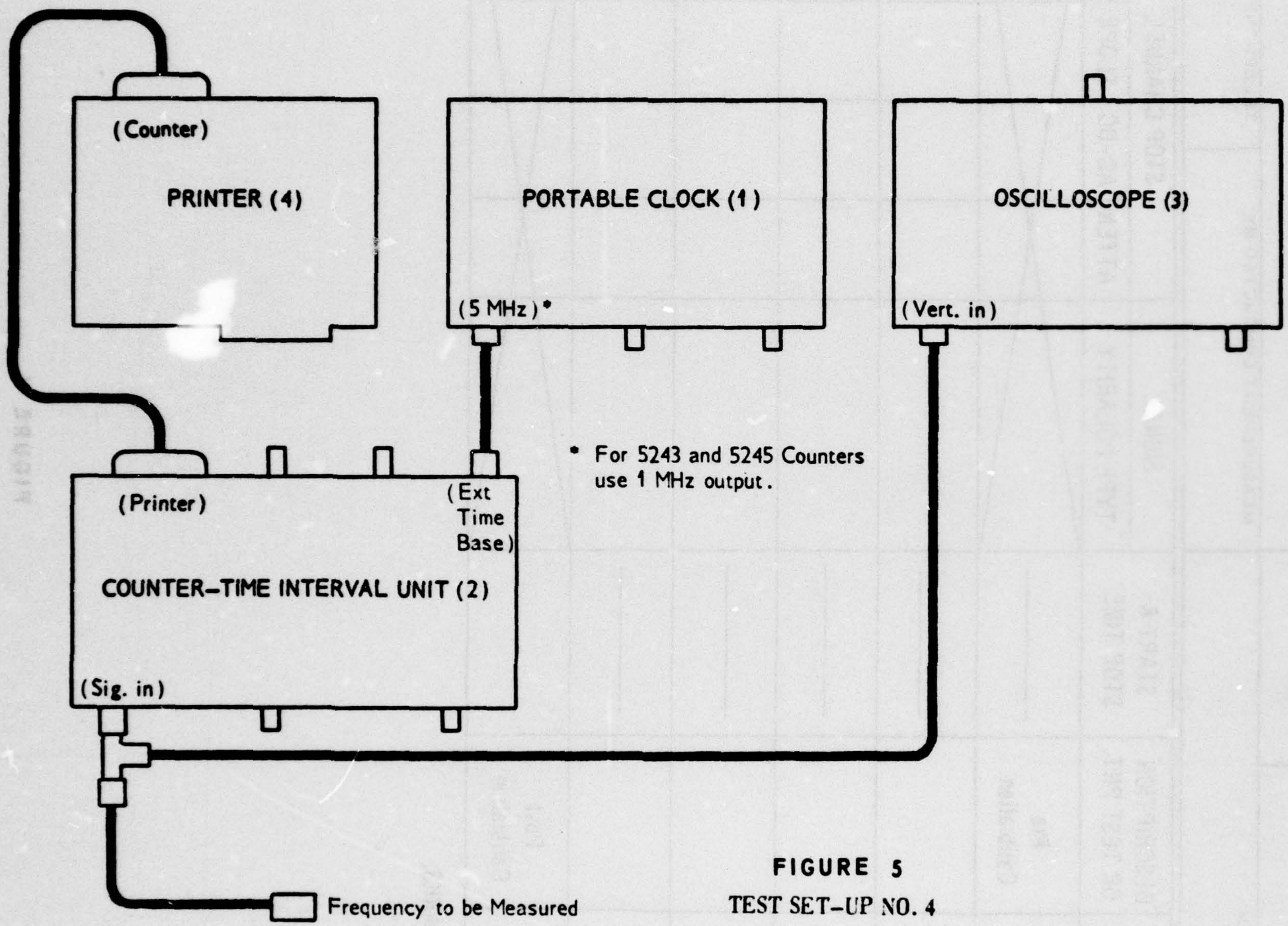


FIGURE 5

TEST SET–UP NO. 4

TIMING MEASUREMENTS LOG

DATE	OPERATION NO.	TEST LOCATION	
SYSTEM		MEASUREMENT CONDUCTED BY	TELEPHONE NO.

RUN NO.	DESCRIPTION OR TEST PNT.	START & STOP TIME	SIGNAL	STOP CHANNEL			
			TYPE POLARITY	ATTEN	AC-DC	SLOPE	LEVEL
1	Pre Calibration	______					
2		______					
3		______					
4		______					
5		______					
6	Post Calibration	______					

REMARKS:

FIGURE 6

5.2 IMPROVING TELEMETRY TIMING ACCURACY

User requirements specified that to provide digital telemetry data must be time tagged to within an absolute ± 100 μsec. of coordinated universal time (UTC). The requirement based on the need for direct comparison of inertial guidance and radar data. Standard telemetry equipment in common use at most sites could not meet this accuracy due to the accumulation of timing uncertainties. Timing uncertainties associated with standard receiving, recording and processing equipment exceed one millisecond. While uncertainties could be reduced through measurement and equipment procurement, more accurate results can be obtained from a simple equipment modification. Examples using the Minuteman system are given to illustrate the technique.

5.2.1 Theory

Sources of Timing Uncertainties - Assume that a particular data bit is received at a telemetry site's antenna feed at epoch time T_0. The digital tape produced from the site's recording must indicate that the bit was indeed received at T_0. Any variation is considered to be the accumulated timing error. Referring to Figure 1, there are eight basic categories of errors which determine the total error. There is a transmission delay ΔT_1, from the antenna feed through the receiving system to the analog recorder head. The station master timing is not perfectly synchronized to coordinated universal time (UTC) and introduces uncertainty, ΔT_2. The Central Time Signal Generator (CTSG) IRIG timing equipment is synchronized to site timing. The accumulative distribution propagation delays are compensated for and the appropriate IRIG time code routed to the analog recorder head. Delays and synchronization error produce uncertainty, ΔT_3. The site's analog recording is then sent to a computer processing facility where serial analog data is converted into formatted digital data. Timing uncertainty, ΔT_4, results from head spacing differences between the recording and playback machines. IRIG standard 106-73 revised Nov. 1975 specifies a head stack placement for even and odd track heads of 1.5" $\pm$ .001". As timing may be recorded on an adjacent track from the data track, there could be as much as .002" displacement between data and timing during playback. At 120 inches per second, this represents a 16.6 μsec. uncertainty. Head skew and gap scatter error

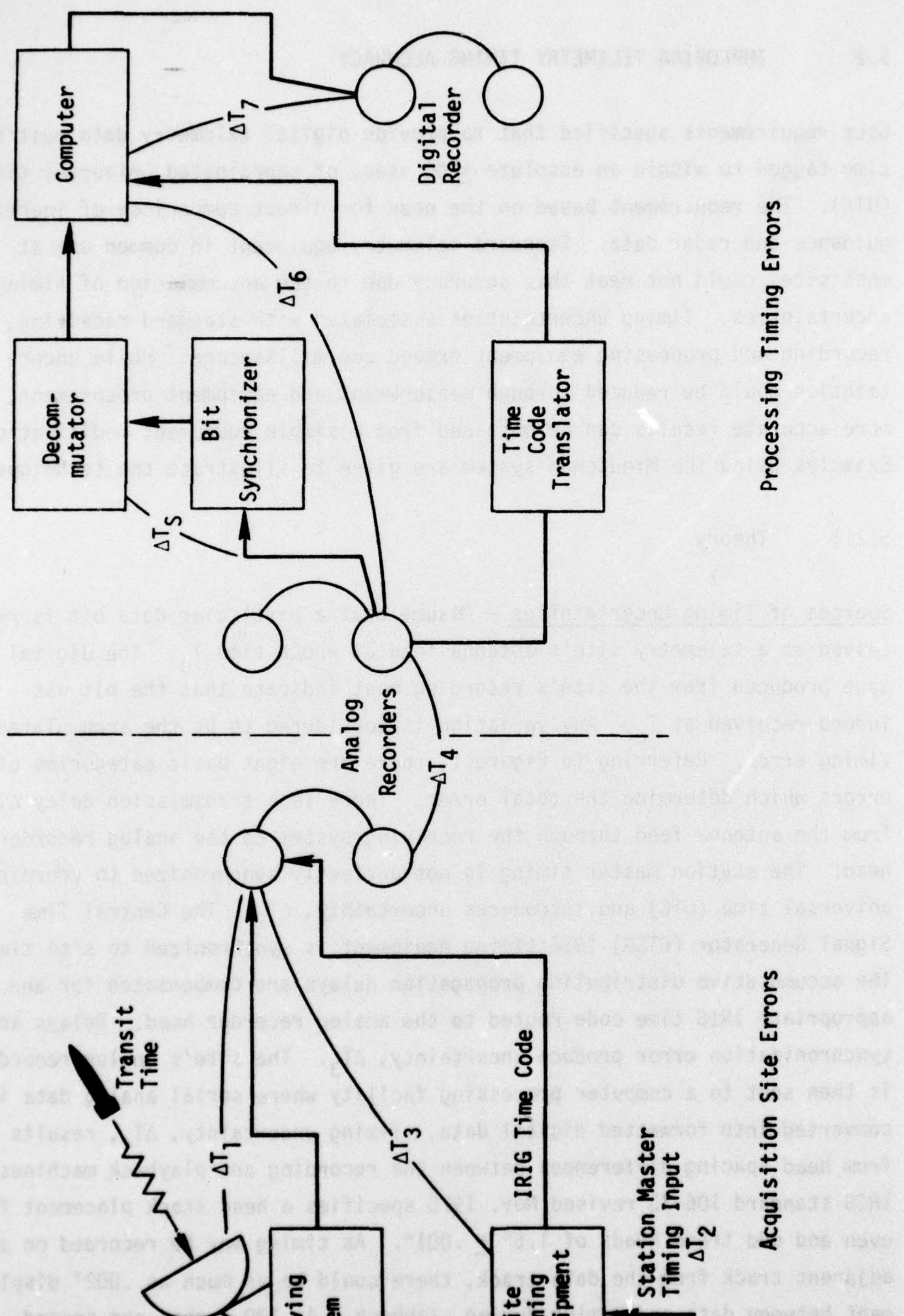


FIGURE 1 SOURCES OF TIMING UNCERTAINTIES

can also be lumped with head displacement. ΔT_5 is the time delay associated with transfer of the data from the analog recorder, through the bit synchronizer and decommutator, to the computer. This is a function of both hardware and software. ΔT_6 is the error associated with locking the IRIG timing translator to the signal from the recorder, and transferring timing to the computer. Two references are helpful.

1. Thomas, L. D. Time Error in Minuteman Telemetry Data, Autonetics T/71/257/201; 1 March 1971.

2. Crane, W. S. Telemetry Timing Accuracies at Vandenberg Air Force Base, ITT/Federal Electric Corporation, Vandenberg AFB, California, 13 November 1970.

Reference 1 provides a discussion of the error and the following conclusions relating to IRIG B synchronization:

- Amplifier inversions can introduce a 500 μsec. uncertainty if the inversion is not recognized and corrected at the processing facility. Normally the IRIG time code on time T_0 is positive going.
- Errors of 400 μsec. or more have been experienced in synchronizing translators to IRIG B timing.

ΔT_7 is the uncertainty associated with inserting timing marks in the digital data. This is primarily a function of computer software and is typically $\pm$ 1 word time. As an example, this would be approximately $\pm$ 78 μseconds of uncertainty in the time tagging of Minuteman PCM data. Use of IRIG A time code typically results in a mean average delay of 7-12 μseconds in addition to the ΔT_7 uncertainty.

Reference 2 documents the cumulative uncertainties of ΔT_4, ΔT_5, ΔT_6 and ΔT_7. An analog tape was played into the same processing station several times, and then played into four other processing stations. Octal dumps were made from each data run, and the timing associated with discrete data words noted. Pertinent results are summarized in Table 1 and demonstrate that processing errors along range from 100 to 1,000 μsec. Reference 1 provides estimates of intersite timing differences experienced during launch support. The estimates

Table 1 Processing Error Summary from Reference 2

Timing Playback Mode	Average timing variances between data produced on four computer processing facilities, referenced to the results obtained from a fifth facility.	Timing variances from successive data runs on the same computer processing facility.
Normal polarity unfiltered	156 µsec.	100 µsec. typical 1,000 µsec. maximum
Inverted polarity unfiltered	625 µsec.	
Normal polarity filtered	1,017 µsec.	
Inverted polarity filtered	575 µsec.	

Table 2 Timing Variances between Computed Event Time and Digital Data Event Time

	Launch 1	Launch 2
Station A	582 µsec.	179 µsec.
Station B	692 µsec.	114 µsec.
Station C	130 µsec.	47 µsec.

were obtained by designating one station as a reference, computing transit times from radar or inertial guidance data, and calculating the expected reception time of discrete events at each site. The expected reception times were then compared to the actual data and differences computed. Pertinent results are summarized in Table 2 and indicate errors from 47 μsec. to 692 μsec.

Thus, from an analysis of the hardware, software and the studies in references 1 and 2, it is concluded that the timing errors accumulated on digital tapes will average several hundred microseconds, and may exceed one millisecond.

5.2.2 Test Procedure

On high bit rate PCM programs, excellent accuracies can be obtained with existing equipment and modification of applicable scan software. A Time Correlation Generator was designed and implemented to measure the timing errors. Also, a spare track on one analog recorder is needed. The technique consists of inserting a timing marker word in a predetermined format in the data stream in real time. Refer to Figure 2. The telemetry station is patched for normal support, except that the video output of one data receiver/combiner is connected to a bit synchronizer. The NRZ and clock outputs are used to provide Bi-ϕ data and clock. (Some synchronizers include this feature.) Conversion to Bi-ϕ data avoids the problems associated with NRZ recording and produces a data stream with the same bit time as the clock signal. The Bi-ϕ data is recorded on tape until a 1 pps timing pulse is received. The pulse triggers a electronic switch which selects the clock signal rather than data. After about one-half word time, the switch resets and selects the data signal. The result is that a sequence of all "ones" (or all "zeros") is inserted in the data stream. Figures 2B and 2C illustrate the logic and schematic of the switch used in development and testing on the Minuteman program.

To use the timing markers, the tracks are processed normally and scans of the digital tapes obtained on a mean time bias and standard deviation are computed. The all "ones" sequence is easily recognized by the computer software and the first "one" marks the frame, word and bit which corresponds to the station's 1 pps pulse. The timing on the normal data is then computed for the same frame,

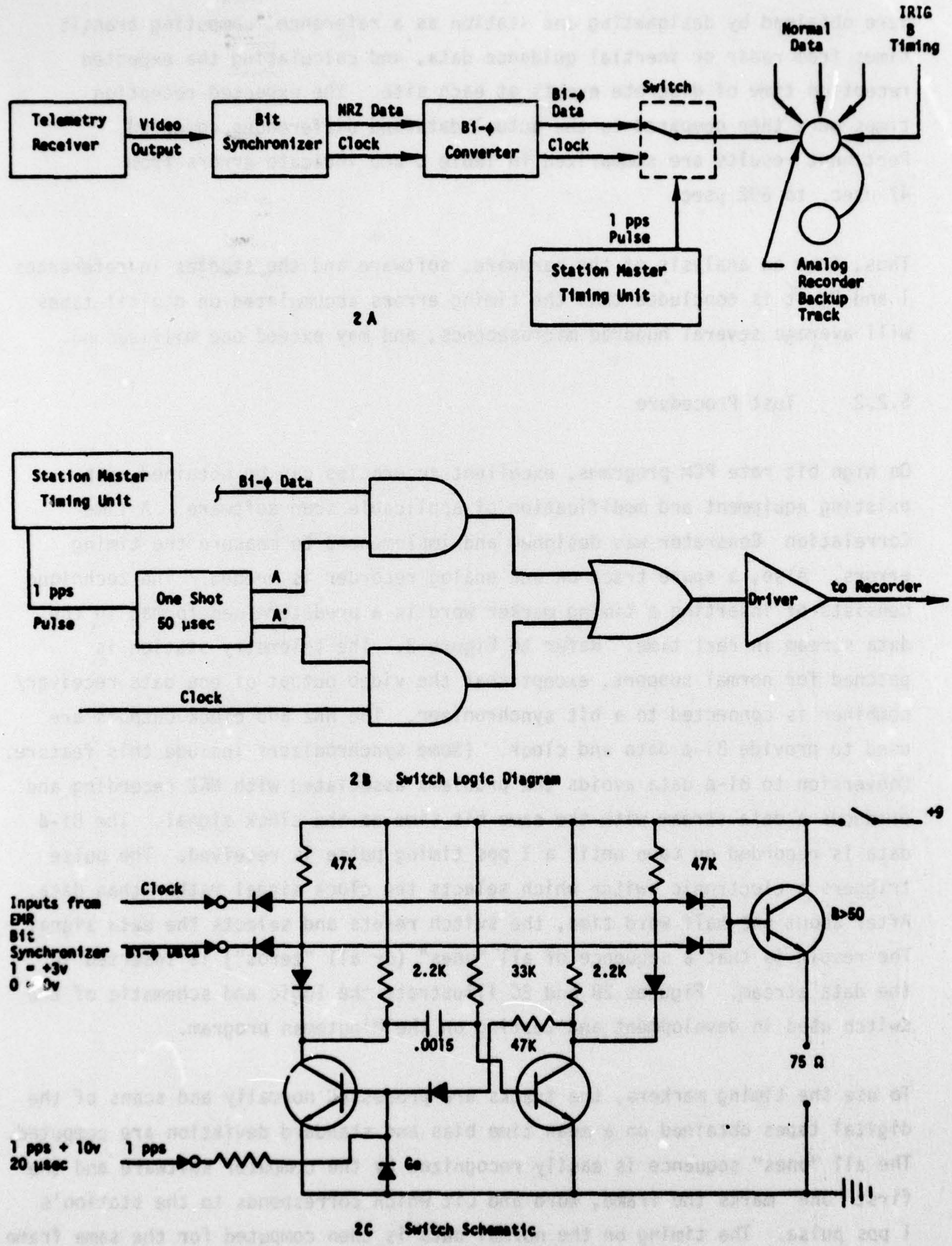


FIGURE 2 REAL TIME TELEMETRY TIMING MARKER SYSTEM

Figure 3 Minuteman Timing Bias Computation

A. Timing Track Octal Dump Evaluation

Step 1. Word sync error noted in major cycle 543, minor cycle 2, word 360.

Step 2. Octal dump evaluation is:

Status

Word 360 3400 35472577

Word 361 3000 77762637

All "ones" timing marker

5 7 7 7 7 7 6

101 111 111 111 111 111 110

01 Transition

Station 1 pps Pulse ± 1 Bit

B. Data Track Octal Dump Evaluation of Major Cycle 543, Minor Cycle 2

Millisecond Marker for 09:51:23.999

Word 352 3040 43072617

True Station Time is 09:51:23.000

Indicated Timing is 09:51:22.999

plus $7\frac{5}{6}$ word times

@ 78 μsec. per word

Word 360 3400 35472401

C. Timing Bias Calculation

Timing bias is 09:51:23.000 - 09:51:22.999611 = -389 μsec.

D. Adjustment of Timing Bias to Range Time

Station master timing delay is estimated at -20 μsec. Receiving system delay (including bit synchronizer) is measured at 8 μsec. Corrected timing bias is -417 μsec. referenced to range time.

word and bit. The difference is the cumulative timing bias on the digital data tape. Figure 3 shows a typical computation for a Minuteman tape. This time bias scan is produced per Sodim Data Item 242.03.

Once the timing bias is determined, the digital tape can be corrected. However, this is seldom necessary as subsequent computer processing usually includes provisions for bias correction.

Computer Processing Considerations - In computerizing the bias computations, one problem of significance was noted. The all "ones" sequence was sometimes inserted between all "ones" syllables. This complicated the search routine for the marker word and introduced an uncertainty as to which of the "ones" in the combined pattern was the marker bit. Analysts rejected these cases and used only the "good" samples such as the one shown in Figure 3. To maximize the samples available and to simplify the programmer's task, a modified switch was developed which inserts four zeros after the 1 pps pulse is received and then change to all "ones" for one word time. The zero to one transition will then be used as the reference bit.

Software was developed to designate whether the timing marker occurred during the first or second half of a word. This reduces the computer processing uncertainty to one-half word time, approximately $\pm$ 39 μseconds. Efforts are underway to designate the correct word syllable. These efforts have produced computerized bias computations for Minuteman tapes accurate to within $\pm$ 50 μsec.

Computer processing facilities have developed merging programs to provide a composite tape from the best data sources throughout the flight. Several of the programs merge data frame by frame with all data referenced to one site by transit time correction. Where such merging is accomplished, timing bias of the composite tape can be obtained by comparing its octal dump to the reference site's timing marker track.

Because of the User's need for increased time tag data accuracy requirements, a new improved design is in the process of being implemented to supplant the

Time Correlation Generator. The unit designated the Time Insertion Unit (TIU) will have the following capabilities:

- Inserts Timing words with 1 microsecond resolution every frame or subframe.
- Location of Timing words can be changed for different launch operations and PCM formats.
- Normally Timing word time is referenced to leading edge of frame sync pattern recognition bit.
- Operates from either external decommutation system or self contained frame or incrementing subframe pattern recognition.
- Timing derived from Cesium Standard included with system.
- Self test capability (1MBPS internal PCM simulator).
- Extra filler bits for site ID, link number, etc.
- Expansion capability for inclusion of 36 extra bits for telemetry $\dot{R}$ information etc.
- Serial NRZ and Bi-ϕ output formats.
- Optional parallel output of timing plus expansion capability information.

Figure 4 shows the front panel layout of the TIU. Figure 5 is present a block diagram of the TIU as it will be applied in a telemetry acquisition system support configuration.

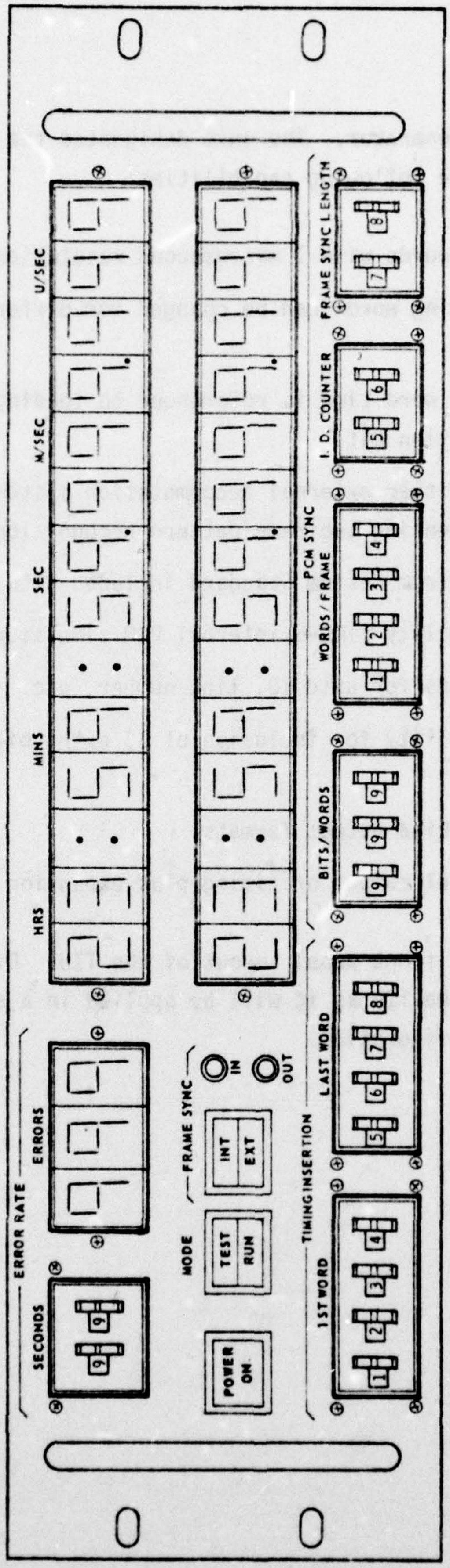


FIGURE 4
Time Insertion Unit

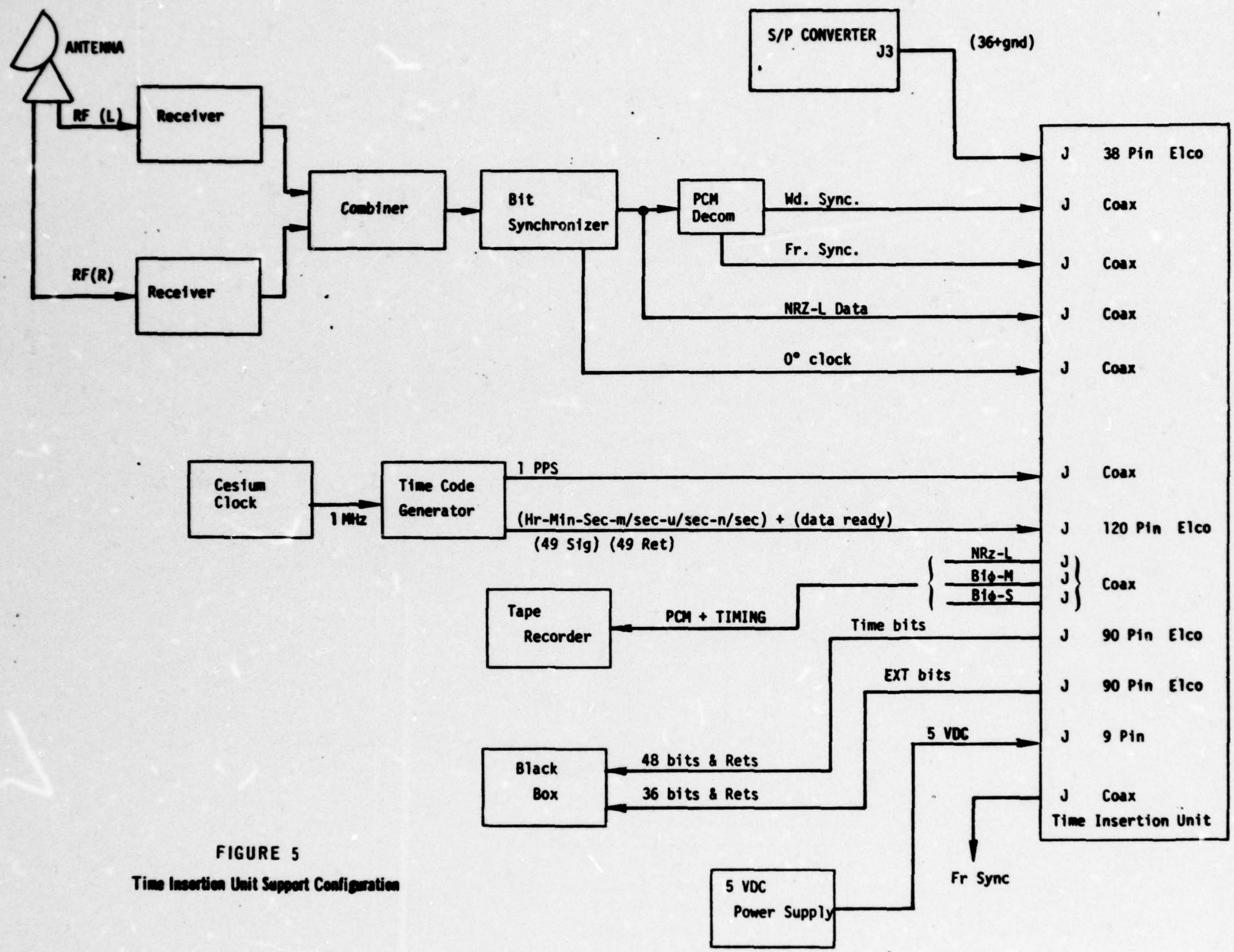


FIGURE 5

Time Insertion Unit Support Configuration

SECTION 6

COMBINED SYSTEMS TESTS

6.1 OPEN LOOP VALIDATION SYSTEM

6.1.1 Theory

The open loop validation system is a general purpose simulation system which may be either computer controlled, as in the case of PCM, or manually controlled, as in the simulation of both PCM and analog data or hybrid combinations of both PCM and analog data. The simulated data is generated within the DC-21 facility and transmitted to remote sites such as TRS or CTLI, by a 10 watt S-band transmitter located at Range Data Facility (RDF) Bldg. 7000. Receiving sites process the data using an actual launch configuration, then relay the data back to the RDF facility via the range data microwave system. The simulated data may then be decommutated or discriminated and sent to the computer systems or display systems for further processing and display. In addition to the processing and display functions at the RDF, DC-21 facility may perform a bit by bit comparison between transmitted and received PCM data, and process FM/FM data to determine added noise content. The open loop validation system may also be used for noise power ratio (NPR) testing. The system has the capability to simulate any telemetry link currently supported by the SAMTEC.

A block diagram of the open loop validation system is shown in Figure 1. Interface between the validation system, the CDC 3300 computer system and other data system areas is provided by a 20 x 20 switching matrix.

6.1.2 Test Procedure

Validation testing may be accomplished at two or more sites simultaneously however, it is recommended that testing by the open loop validation system be scheduled and accomplsihed on a site by site basis. Testing is this manner will allow the system operators to adjust signal-to-noise ratios to meet

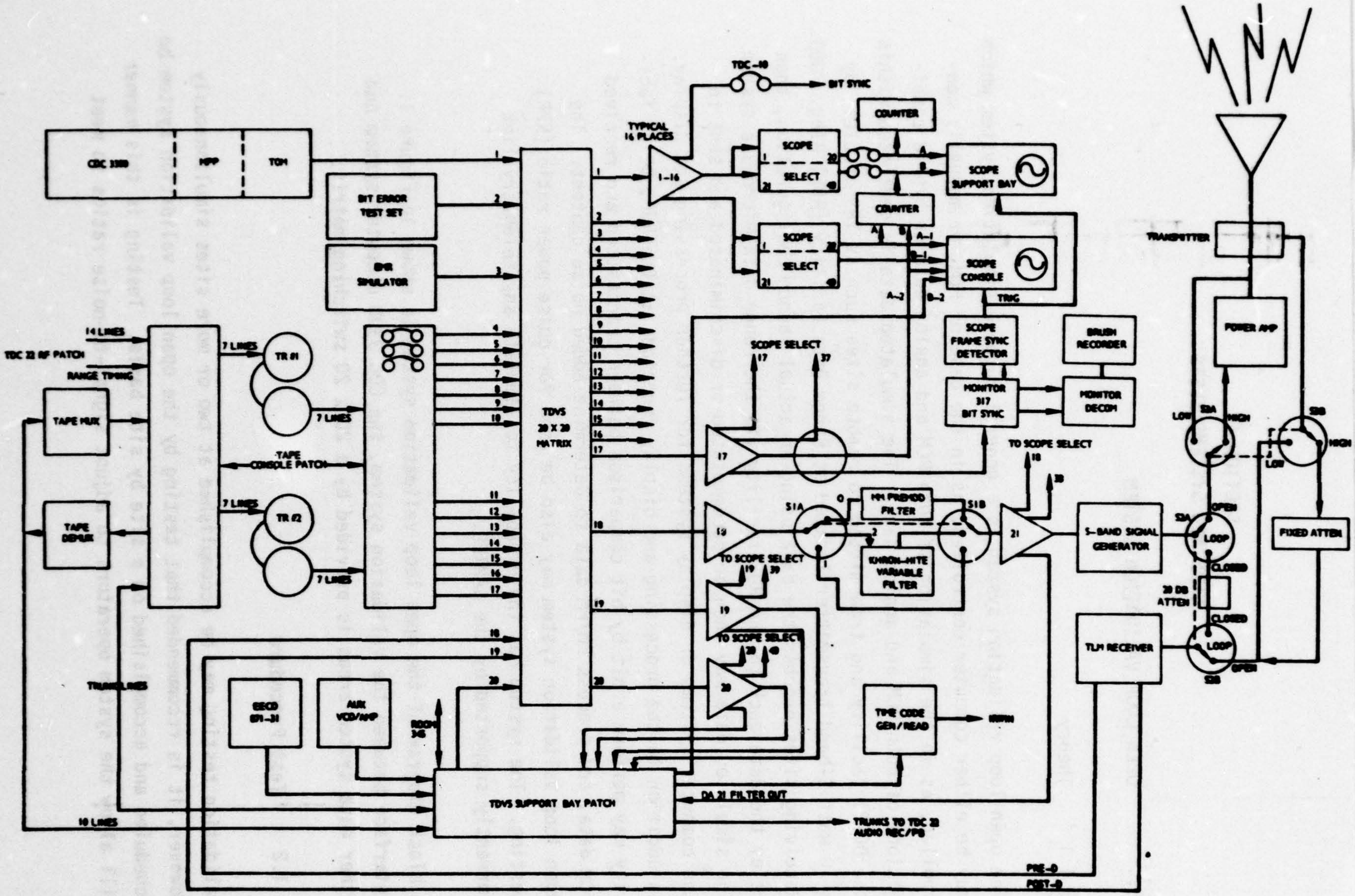


FIGURE 1 OPEN LOOP VALIDATION SYSTEM

the individual site test requirements. The following tests have been designed to be accomplished in a minimum of time and as close to scheduled lift-off times as practical. Testing should be accomplished in full mission configuration with no patching or equipment configurations required to reconfigure for mission support.

The open loop validation system (OLVS) operator will first set up his station to simulate each telemetry link in sequence, i.e. PCM simulators adjusted for bit rate and code type, notch noise generators configured for correct bandwidth and notch requirements to simulate FM/FM or hybrid links. Each link to be simulated should be set up and checked out using the validation receiver before interface with the remote site. Matrix switching requirements should be prepunched on punch cards for rapid sequencing from one configuration to another during the interface. Since the receive site is in mission configuration, no action is required on the part of that site other than antenna orientation and signal acquisition reporting. During normal testing, the test conductor (OLVS operator) will interface with the remote site and the microwave controller in the resolution of any problems which may be noted during the testing.

Figure 2 is a general block diagram showing a possible signal flow from the OLVS, through the acquisition site and microwave, to the data center, then back to the OLVS. Each test required to validate a system is conducted as described in the Range Planning section of this manual so just a general sequence of events is presented here rather than the actual test sequence.

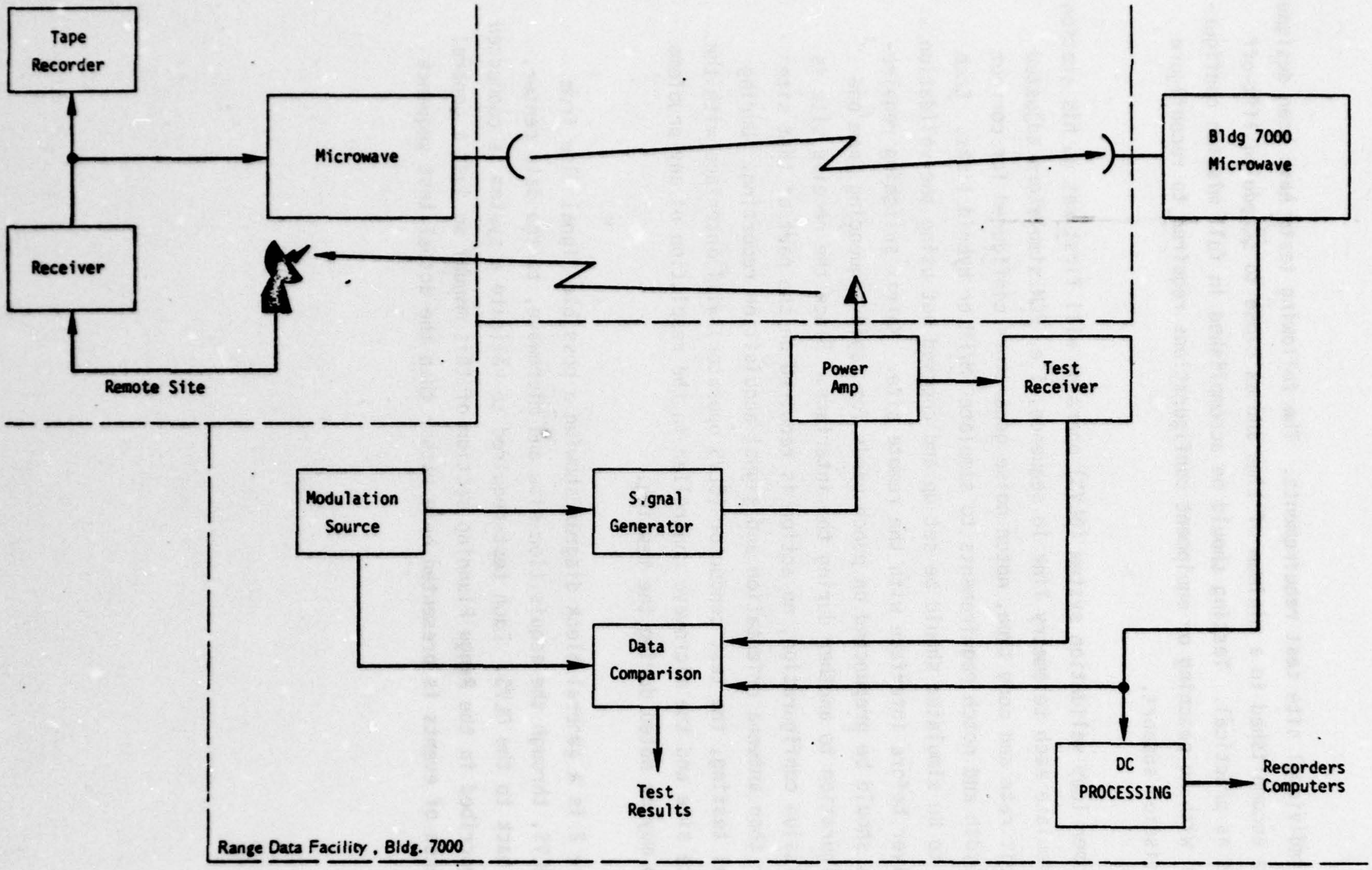


FIGURE 2 TEST CONFIGURATION

OPEN LOOP VALIDATION
EVENT SEQUENCE

	Action	Response
1.	OLVS operator sets up simulation equipment per the OD requirements and verifies his set up by comparison of his generated spectrum with the appropriate simulation spectrum shown in the planning section of his manual and by bit error rate validation through his validation receiver. OLVS system does not radiate signals during this step.	None
2.	OLVS Operator: Operations control, This is DC-21 OLVS, request permission to radiate on links ____, ______ and ______ commencing at ______ hrs and terminating at ______ hrs. Radiation is for the purpose of open loop validation testing for Operation No. ____ .	Operations Control: Permission granted.
3.	OLVS Operator: TRS, this is OLVS, are you configured for open loop validation testing on links ___, ___ and ___ for Operation No. ___	TRS Controller: TRS is configured. All required antennas are pointed at your location.
4.	OLVS operator radiates at maximum power and required modulation to simulate the first link.	TRS Controller: TRS has AOS on link ___ signal strength is ___ over ___ system 1 and ___ over ___ system 2.
5.	OLVS Operator: Bldg. 7000 Microwave, This is OLVS, do you see TRS link ___ data:	Bldg. 7000 Microwave: We have TRS, link ___ data on microwave line ___ to you.

Action	Response
6. OLVS operator confirms receipt of dta and records notch depth (for notch noise test) or bit error rate for PCM tests. For PCM testing, the operator decreases his radiated power while observing the bit error rate monitor until a BER of $1X10^{-6}$ is observed for PCM bit rates of 200 k bits, or greater or $1X10^{-5}$ for bit rates less than 200 k bits/sec.	
7. OLVS Operator: TRS, this is OLVS, I see $1X10^{-6}$ data at a radiated power of ____ watts. What is your link ____ signal strength?	TRS Controller Signal strength for link ___ is ____/____ system 1 and ____ over ____ system 2. OLVS operator records signal strength.
8. OLVS operator terminates RF radiation, reconfigures his station to simulate the next link then increases radiated power to maximum.	TRS Controller: TRS has AOS on link ____. Signal strength is ____ over ____ system 1 ____ over ____ system 2.
9. OLVS operator repeats steps 5 through 8 until all links have been tests.	
10. OLVS Operator: Operations control, This is DC-21 OLVS, all validation tests are completed. My simulation transmitter is turned off.	Operations Control: Confirm testing complete.

6.2 TELEMETRY VALIDATION SYSTEM

6.2.1 Theory

The primary function of the validation system is to verify that the telemetry receiving system is operating in an acceptable manner. In order to determine what is acceptable performance, it is necessary to consider the role of the receiving system in the overall telemetry link.

Consider a transmitter remotely located from a receiving system. If the transmitted signal carries information, it is necessary to determine the information degradation caused by the noise and distortion in the receiving system. If the degradation is within acceptable bounds, the receiving system is performing satisfactorily. As distortion and noise effects are directly related to the received signal level, the ability of the antenna system to perform properly must also be verified. The receiving system is required to perform two basic functions:

> Provide a prescribed signal-to-noise ratio for a given amount of RF energy incident on the antenna.
>
> Introduce less than a prescribed amount of distortion in the received information.

<u>Signal-To-Noise Ratio</u> - In order to determine the signal-to-noise ratio which a receiving system should provide, consider a transmitter at a distance R from the receiver. The transmitter has an antenna with a Gain G_T in the direction of the receiving antenna. The transmitter radiates power P_T watts, at a frequency of f Hertz. The receiving system model has an antenna with a gain G_R in the direction of the transmitting antenna; a connecting cable or waveguide with loss L_1 between the antenna and receiver (the loss L_1 represents all losses between the feed and the receiver including hybrid, directional coupler, cable, connector, VSWR losses, etc, L_1 = input power/output power). The "receiver" includes the pre-amp, down-converter, multicoupler, tuned receiver, and all interconnecting cables. The interface point between the cable and the "receiver" is at the pre-amp input. The receiver has an overall noise figure N_{FR}, and the final IF bandwidth is B Hertz.

Using the above model, received signal-to-noise ratio in the final IF is given by the expression:

$$S/N = \frac{P_T G_T G_R}{\left(\frac{4\pi R f}{C}\right)^2 K T_S B} = \text{signal-to-noise ratio in an IF bandwidth of B Hertz}$$

where C is the speed of light (in the same unit as R)

π is constant (3.1416...)

K is a constant (1.38×10^{-26} watts/M^2Hz), and

T_s is the system noise temperature, in degrees Kelvin.

All other parameters have been previously introduced. T_S can be estimated from the following relationship:

$$T_S = T_{sky} + T_1(L_1 - 1) + 290(N_{FR} - 1)L_1$$

where T_L is the temperature of the antenna to receiver cable.

However, T_S is difficult to obtain accurately by individual measurements as L_1 cannot be measured (the antenna feed is a hypothetical point within the hardware); the cable temperature may change with ambient variations; T_{sky} changes with elevation angle (only slightly above 10^o); and it is difficult to measure the noise figure of the composite receiver accurately. Also, measuring G_R is a cumbersome procedure.

Notice in the expression, however, that signal-to-noise ratio depends on the ratio of G_R to T_S (antenna gain to system noise temperature). It is fortunate that the ratio (defined as the system figure of merit) can be simply and accurately measured. This avoids the problem of determining G_R, L_1, T_L, T_{sky}, and N_{FR} independently. Rather, the signal-to-noise ratio which will result from a particular transmitter configuration can be accurately determined from G_R/T_S and B alone. Both terms can be easily measured.

One other point of significance should be noted. If two receiving systems are co-located and are receiving energy from the same transmitter, if the G_R/T_S of the first system is twice as large as the second, then (if the IF bandwidths are identical) the signal-to-noise ratio in the first system's IF will be twice as <u>great</u> as the signal-to-noise ratio in the second system's IF.

As signal-to-noise ratio is usually expressed in decibels (dB) it is useful to define a parameter $M' = 10 \log_{10} G_R/T_S$. Thus if the M' of the first system is 20, and the M' of the second system is 17, then the signal-to-noise ratio in the first co-located system would be 3 dB greater than the second, etc.

The "acceptable" value of G_R/T_S will be different for each system, polarization, and frequency considered. Consequently, the pass/fail criteria can best be established by averaging results taken over a several month period, and applying a ± 1 dB tolerance to the average. System design should be investigated if larger variations are consistently observed.

To summarize, the overall performance of the system from antenna to final IF can be determined by measuring one parameter G_R/T_S. Further, G_R/T_S and B alone provide all the information required for predicting the signal-to-noise ratio in the final IF. Finally, the parameter $M' = 10 \log_{10} G_R/T_S$ is useful in that it allows a direct comparison of systems in terms of IF S/N expressed in dB.

<u>System Distortion</u> - While G_R/T_S gives us all the information needed to verify antenna gain and system noise levels, it does not provide data on system distortion. That is, it is possible to have a satisfactory signal level and still provide garbled information. Consequently, additional testing is required to verify information quality. At present, several information transmission schemes are in common usage. Pulse Code Modulation (PCM) uses binary "1" and "0" levels. For such signals, the distortion of significance is basically ringing and time base fluctuations. The test technique is simple in concept; simulate the expected signal and determine if a specified bit error rate is obtained at a prescribed signal-to-noise ratio.

FM/FM Reception - Another common information system is FM/FM. In this system, subcarriers are frequency modulatd by analog signals, and the composite of the subcarriers FM modulates the RF carrier. The RF spectrum appears to be a "hump" of random noise. The distortion of special significance in FM/FM reception is intermodulation distortion caused by system nonlinearities, etc. It is difficult to simulate a particular modulation scheme, as there are a larger number of subcarrier combinations, deviation, ratios, analog driving signals, etc. It is easier to perform a more general test which is valid for all configurations. This consists of FM modulating the RF carrier with wideband noise; notching out narrow segments of noise, and determining the "depth" of the notches when the RF signal is demodulated. Nonlinearities cause the notches to "fill in". The notch depth can be related to FM/FM subcarrier distortion.

SGLS Reception - Another information system is used in the so-called SGLS technique. Up to three subcarriers are modulated with PCM and or analog data. The composite of the subcarriers PM modulates the RF carrier. Testing consists of modulating the subcarriers with PCM and determining distortion effects on the individual subcarrier outputs as outlined above.

Solar Testing - Since the sun constantly radiates energy throughout the RF Spectrum, the amount of energy radiated can be carefully measured several times a day by systems which are accurately calibrated for such purposes. The energy levels for several commonly used frequencies are sent by teletype to interested agencies. On certain days, the energy level may change from hour to hour due to solar flares. Such days are called "red" days to alert user agencies that measured values are not reliable. On quiet days, however, (days with no flares) the radiation levels are essentially stable over an eight hour period. Such days are called "green" days.

In order to use the sun's energy, a very simple technique is employed. The antenna is first pointed well behind the sun in azimuth, and the amount of power in the receiver IF is measured. The antenna is then pointed at the sun, and the power change in the IF is noted. The change in power and the current value of energy being radiated from the sun provides the information required to calculate G_R/T_S.

With the antenna pointed away from the sun, the power in the IF $\doteq P_1 = KT_sBA$. When the antenna is pointed at the sun, the power in the IF $\doteq P_2 = K(T_{sun} + T_s)BA_2$. ($A_2$ is used to represent the fact that system gain may not be constant, i.e., over a wide dynamic range the input/output relationship may not be linear.) If we force the receiver gain to remain constant by replacing the normal AGC type receiver with a linear pass band amplifier, gain will be constant, i.e.

$$A_2 = A_1. \quad \text{Consequently } \frac{P_2}{P_1} = \frac{T_{sun}}{T_s} + 1$$

Note that $\frac{P_2}{P_1}$ represents the power change which occurs when the antenna is moved from the sky to the sun.

$$\text{Also, } T_{sun} = \frac{FG_R C^2}{8\pi K L_A f^2}$$

where F is the current value of solar flux radiated at frequency f, and L_A is an antenna beamwidth correction factor, $L_A = 1 + .38 \left(\frac{.5}{\theta}\right)^2$

where θ is the 3 dB beamwidth of the antenna.

This compensates for the fact that the sun is about 0.5° "wide", and not all of its energy is received on a constant antenna gain. F is obtained by converting the solar flux from the 2.8 GHz reading (provided by the measuring agency) and converting the value to the frequency of interest by using the relation F.

$$\text{Consequently, } G_R/T_S = \frac{P_{2-1}}{P_1} \; \frac{8\pi K f^2}{F C^2} \; \left(1 + .38 \left(\frac{.5}{\theta}\right)^2\right)$$

The validation system measures P_2/P_1; uses the 2.8 GHz flux value and converts it to a designated frequency; applied the L_A correction factor using antenna beamwidth, and computes $10 \log_{10} G_R/T_S$.

Pitfalls In Solar Testing - It is well to consider some of the potential pitfalls encountered in solar testing. Values obtained on "red" days may be considerably in error. *On "green" days however, excellent results can* be obtained at elevation angles above 10 degrees. Below 10 degrees, system noise temperature rises rapidly, and significant atmospheric attenuation occurs. Above 10 degrees, not even heavy rain and fog will cause a significant error greater than one dB. The most common error which occurs in the field is that "receiver" gain changes between cold sky and sun readings. This is not surprising, as the system gain must exceed 100 dB (to raise the level sufficiently for power meter readings). The validation system avoids the problem by verifying that the power reading on the sky remains the same before and after the antenna is pointed at the sun. This is a cross check to verify that gain has remained constant.

Another common testing error is to use a peak or average reading instrument to obtain power reading. Only true RMS instruments provide accurate results. The validations system of course, has an excellent RMS meter.

It has been hypothesized that solar testing would be in error because the antenna fails to autotrack the center of the sun. In practice, autotracking antennas appear to closely track the sun's center. In case of doubt, the autotrack positions should be checked against the manual or designate position which provides the highest I.F. power reading.

NASA has estimated that a property conducted solar test will provide a value of G_R/T_S that is accurate to within 10%. (This corresponds to $\pm$0.4 dB S/N accuracy). Direct comparison of Solar and radiometric testing has shown that solar results agreed with the complicated and cumbersome radiometer method to within $\pm$0.2 dB. Radiometer testing uses stars rather than the sun; if properly conducted the method is highly accurate.

Of special importance to those charged with maintaining the receiving site is the fact that properly conducted solar tests provide repeatable results. Variations in excess of $\pm$0.5 dB can be attributed to system variations. Thus, solar testing provides unprecendented speed and accuracy in determining system "health". One point of caution should be made, however, although solar test give accurate, repeatable answers, it should

not be assumed that the G_R/T_S value obtained at one frequency will be the same at another frequency. It is impossible to design a feed with the same gain across a wide band and the same is true with regard to system noise temperature. Consequently, in order to obtain a true picture of system performance, tests must be run at closely spaced frequencies across the entire band of interest. Before an operation, the system should be checked at the operational frequency. The capability to make many tests at many frequencies by solar testing is an important feature, for G_R/T_S may vary significantly across the band in a normally functioning system. Such flucutations may not be documented in radiometric testing, where, because of the complexity of performing the tests, results are usually obtained at only low, medium, and high band frequencies.

Note also, that variations of solar test results from week to week are not due to test result errors. Rather, the variations are primarily due to system changes. It is common for G_R and T_S to change in only a few hours. A primary use of solar testing is to verify that the changes have not become too large, i.e., that the system continues to perform within normal bounds of expected performance.

Bit Error Rate Testing - In order to verify that the receiving system is not unduly distorting transmitted information, bit error rate testing is employed for PCM links. The first consideration is to simulate the RF transmission of the expected signal. The same PCM code, bit rate, pre-mod filter, modulation scheme and RF deviation are selected. There are, however, a nearly infinite number of format schemes, so rather than simulate a particular data format, a "random" sequence which repeats each 2047 bits is employed. This sequence is called a pseudo-random sequence as the 2047 bits occur in a random fashion, but the format is not truly random as the same 2047 bit sequence repeats over and over. It has been found that such a sequence closely approximates the results which occur on most communications links when actual data is transmitted. This is not true of 1-0 type patterns, or simulated patterns containing frame sync, special word and a common word.

Referring to Figure 1, The RF is input to the receiving system (preferably at the par-amp input) and the receiving system output is checked for errors. The video (if the operational system provides a pre-d output, it is con-

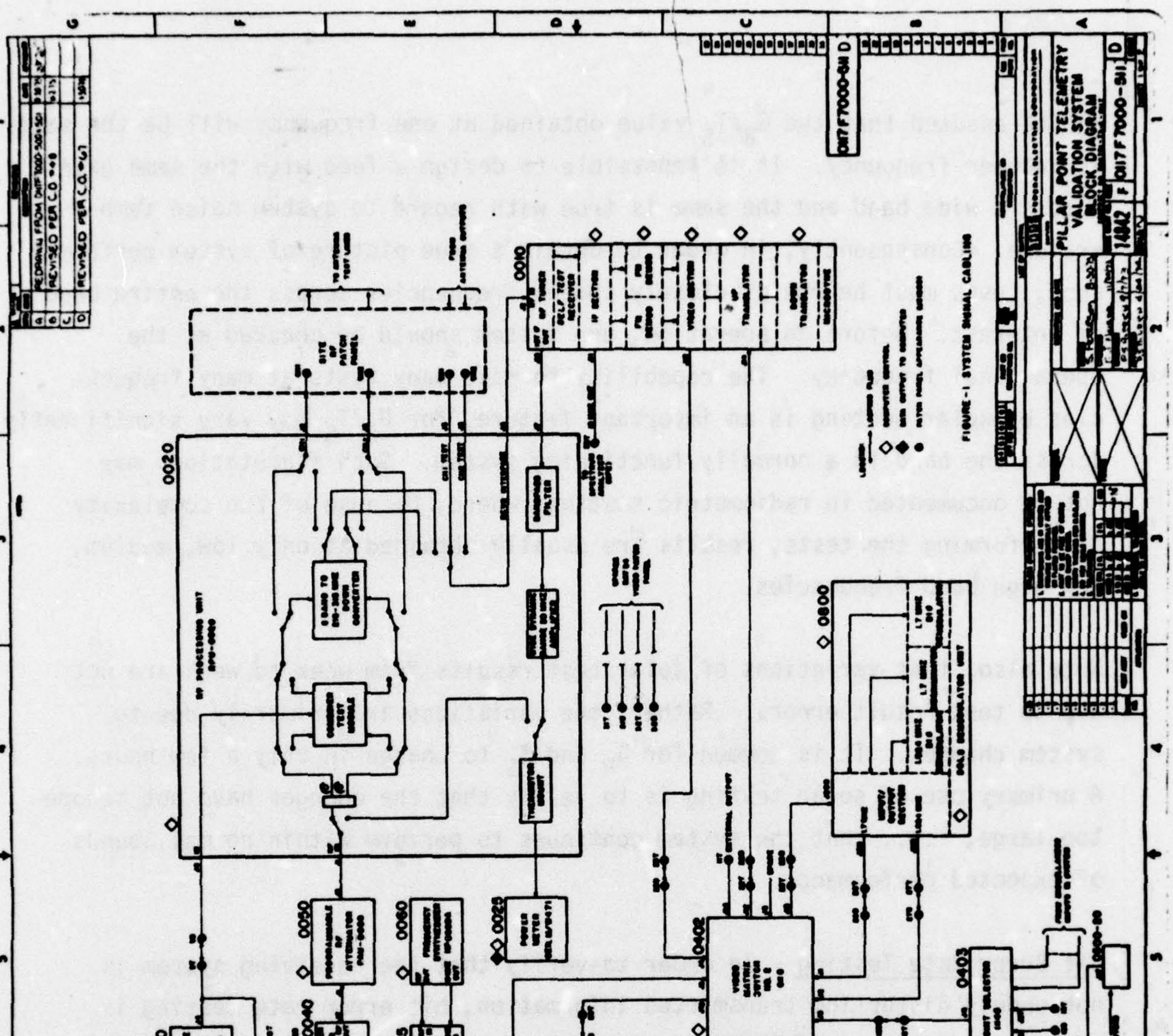


Figure 1

Validation System Block Diagram

verted to video in the validation system) is patched to the bit synchronizer (U/C 0200) which shapes the data and also provides clock pulses in synchronism with the data pulses. Shaped data and clock pulses are then fed to the Bit Error Rate Test Set, U/C 0100, which compares the 2047 bit sequences that arrive, to the 2047 bit sequences which were expected; i.e., the BER test set knows what sequence to expect, and each bit which deviates from the expected is accumulated as an error. The monitor then provides the number of errors in one million, 100,000, 10,000 etc., as required. It should be noted that the BER test set receiver is not synchronized with its PCM transmitter. This is important, as data recorded on tape can be analyzed at any processing station possessing a suitable error rate monitor. This feature allows the evaluation system to evalute the performance of the total system including recorders.

Having obtained a measure of the number of bit errors in a given sample, it must be decided if the receiving system passes or fails; i.e., were there too many errors in the sample? While it would be desirable to compare the error rate versus theoretical expectations, this cannot always be done. Theory presumes optimum IF bandwidths, linear demodulation, perfect bit synchronization etc. In field work, it is necessary to deviate from such theory and relate to actual results. Consequently, extensive testing has been done of current PCM formats on several different types of receiving systems. Bit error rate versus IF signal-to-noise ratio results have been carefully cataloged in determining whether a given system "passes or fails". It is really being compared against other existing systems.

"Pass-fail" criteria can be based on either IF signal-to-noise ratio or on the power level injected to the parametric amplifier input which results in the measured bit error rate(s). When the antenna is pointed at the sky, the power in the validation system receiver IF = $P_2 = K(T_{sun} + T_s)BA_2$, (terms were previously explained). If the RF power is increased until the power meter reading doubles (increases 3 dB), the RF power now equals the noise power. This is defined as 0 dB S/N, in a bandwidth of B Hertz. If the RF attenuator is decreased 13 dB, a 13 dB S/N will result, etc. This, the 0 dB check calibrates the RF attenuator in terms of signal-to-noise ratio. The Validation System can then compare receiving system results SNR to "pass/fail"

criteria stored in a memory simply by using the 0 dB attenuator setting; the attenuator setting which provides a particular BER and the "pass/fail" results. The Validation System also converts the S/N to the nominal bandwidths of the data receiver. That is, 0 dB in the validation bandwidth of 2 MHz will be 3 dB in a receiving system bandwidth of 1 MHz, etc. The parametric amplifier level is a function of the attenuator setting, signal generator power, and cable losses to the "paramp" input.

Combiner Testing - A combiner, if performing its functions perfectly, will accept two input signals, and output a signal as good or better than the best input. While many combiners perform this function admirably under quasistatic input conditions, none will perform properly if the inputs fluctuate widely and rapidly. In certain telemetry links, rapid fluctuations occur due to atmospheric conditions, vehicle roll maneuvers, flame effects, etc. When such links are to be supported, it is vital to test the combiner under dynamic fade conditions. The RF signal is split into two outputs, equal in amplitude. Each signal is again split into pairs, and one leg of each pair passed through an electronically controlled phase shifter. The signal pairs are resummed and patched to the two inputs (typically RH and LH) of the receiving system. It is possible to cause a fade on the RH (or LH) channel by applying a control voltage to the RH (or LH) phase shifter. In the validation system, 1/2 of a sine wave is applied to the RH channel, and the other half is blocked. The opposite 1/2 of the sine wave is applied to the LH channel. Consequently, the RH and LH channels will alternately fade at the rate of the input sine wave (there is one fade per 1/2 cycle of the sine wave), but one channel will always be "on" while the opposite channel is fading.

If the carrier is modulated with PCM Information, then the error rate for one channel only, without fades, can be set to 1 error in 10^4 bits by adjusting the RF attenuator. A perfect combiner always provides an output with an error rate of 1 error in 10^4 bits, or better. However, as the sine wave input to the phase shifters begins to cause fades, the combiner begins having difficulties "deciding" which is really the good channel. As the fade rate is increased, the error rate will eventually increase to 10 errors in 10^4 bits. The sine wave control frequency at which this occurs is referred

to as the "break" frequency. The combiner is now considered "broken" as it is degrading data by about 1 dB equivalent S/N in comparison to theory. The output data is, of course, still better than could be obtained from either input alone.

Having determined the "break" frequency of the combiner, it is necessary to determine if the unit "passes or fails". Missile rolls and flame plasma cause extremely rapid link fluctuations. It has been found through empirical testing that combiners with "break" frequencies exceeding 500 Hertz consistently provide improved data through periods of rapid transients (improved in comparison with RH only or LH only); while combiners with "break" frequencies below 100 Hertz do not. Furthermore, combiners with "break" frequencies exceeding 1k Hertz have been tested. Therefore, 500 Hertz has been adopted as the "pass-fail" fade frequency.

Notch Power Ratio Tests - In FM/FM modulation systems, subcarriers are frequency modulated by analog signals. The subcarrier signals are then linearly summed, and the composite signal is used to frequency modulate the RF carrier. After reception, the individual subcarriers are filtered out and demodulated. Of prime concern is the distortion introduced by the receiving system on the demodulated information. Several approaches have been used to measure the distortion introduced by the receiving system. The most common is the "brute force method" wherein the subcarriers to be supported on the operation are modualted with sine waves, and the total harmonic distortion of the demodulated subcarrier is directly measured. While this method has the advantage of comceptual simplicity, it has several disadvantages as follows:

A complete bank of VCO and discriminators is required to simulate the many formats in common use.

The distortion caused by the VCO and discriminator cannot be isolated from the distortion caused by the receiving system.

Harmonic distortion gives only a partial insight to overall distortion effects.

Notch Power Ratio testing avoids the above problems. Only two units are required, the noise transmitter and the noise receiver. The overall distortions introduced by the receiving system are isolated. As in all system tests, however, the distortion introduced by the RF modulation process is lumped with the final answer, and cannot be conveniently isolated. To avoid this problem, the validation system has highly linear RF modulating equipment. The results include the effects of all distortion contributions of significance, and it can be interpreted in terms of total distortion of the demodulated signals.

A low pass and high pass filter are selected in the noise transmitter. This provides a specified band of noise to the RF trnasmitter which is modulated at a prescribed level. The bandwidth and modulation are selected for compatibility with the subcarrier configuration, RF modulation, and receiver bandwidths to be supported during the actual operation. The demodulated signal is connceted to the noise receiver, and the noise power in a very narrow passband filter is read. Next, the transmitter inserts a band stop filter centered at the same frequency as the passband filter in the noise receiver. The band stop filter is slightly wider than the passband filter, and the noise level in the stopband is lowered by 80 dB or more. However, distortion in the modulation reception, and demodulation causes harmonics to appear, and some fall within the stopband. Hence the "notch" fills in. The noise receiver agains reads the power in the passband, and displays the ratio of the two power readings (one obtained with no stopband filter in the noise transmitter, one obtained with the stopband filter). The ratio of the two readings represents the information desired, and is referred to as the notch power ratio.

The test then continues at several other "notch" frequencies typically selected at the low, mid, and upper frequencies of the designated noise bandwidth. Also, the test is conducted at both low and high RF signal levels.

In order to determine pass/fail criteria, the notch power ratio (NPR) is compared to other actual systems which have also been tested. A "good" receiving system can provide NPR's or 45 dB or more. However, results of 30 dB and less have been obtained, particularly at the higher notch frequencies.

When a tape recorder is included in the loop, results vary from 15 to 30 dB. Obviously, the tape recorder plays a predominant role in introducing distortion, and should be included in the system test. Because of the wide spread of test results obtained from "normally" working field equipment, it is difficult to establish meaningful pass/fail criteria which are applicable to a wide variety of systems. Consequently, each system should be tested over a period of several months and mean value and standard deviations established. Alternately, data users could specify the noise bandwidth, notches to be employed, RF deviations, and NPR requirements to meet data quality needs.

SGLS Testing - The SGLS system is a composite system capable of handling PCM or FM/FM data. Three subcarriers, 1.7, 1.25 and 1.024 MHz can be modulated with PCM or analog signals. The 1.024 and 1.7 MHz subcarriers can be modulated with PCM data of varying bit rates. PSK modulation is employed, (i.e., the PCM data phase modulates the subcarrier and peak deviation is set to $\pi/2$ radians). The 1.7 and 1.25 subcarriers can be frequency modulated by analog signals. The subcarrier outputs are linearly summed (however, not all three are necessarily used simultaneously, but they may be depending on the data requirements) and the composite signal phase modulates the RF carrier at a specified deviation.

The bandwidth requirements can be severe, and recording of SGLS in the pre-d mode may not be feasible in many cases. Consequently, the receiver may merely demodulate the carrier, and the video output (the composite subcarrier signal) be recorded. Tape recorders with a 2 MHz response must be utilized whenever the 1.7 MHz subcarrier is employed. During playback, each subcarrier is separated by filters and demodulated with either a discriminator or PSK demodulator, as applicable. See the U/C 0800 demodulator in Figure 1.

SGLS systems are tested for distortion in the same manner as previously described; i.e., bit error rate checks are run by modulating the subcarriers with a pseudo random PCM code. The primary change of conceptual significance is that the subcarriers are being modulated rather than employing direct carrier modulations. As in the previous tests, all pertinent parameters must be established such as PCM code, bit rate, deviation, etc. Also, the

capability to simulataneously modulate all three subcarriers is provided. Tests results from several SGLS receiving systems have been found to vary greatly, depending on the complexity of the demodulation schemes employed. Consequently, pass/fail (red flag) criteria can best be determined by averaging the results obtained on a particular system.

End to End Performance Capability - A successful solar test verifies that the antenna and receiving system is performing correctly in terms of antenna gain and system noise. A successful bit error rate test or notch power ratio test verifies that the system will provide data of expected quality at a prescribed signal-to-noise ratio or "paramp" input power.

Immediately before an operation, it is advantageous to verify that the complete system is functioning in the final operational configuration. This can be done rapidly and automatically with the validation system, as described in paragraph 6.2.2. For night operations, however, solar testing should be conducted on the preceeding day. After successful testing, the 0 dB attenuator setting should be stored for each link frequency. The 0 dB value shold then be checked before bit error rate testing to assure that a catastrophic failure has not occurred. Variations in excess of $\pm$ 1 dB in a 24 hours period probably signals a system problem.

Troubleshooting - If a system fails to pass solar testing, yet the M' value is within a 2 or 3 units of the nominal value, the problem is most likely in one of three key areas.

The impedance between the feed and pre-amp has increased due to a loose cable; moisture in the cables; a degraded rotary joint (if applicable); etc. Only on rare occasions will structural or feed misalignment cause problems on a system which has been performing satisfactorily. (On new or modified systems, such effects must not be discounted, however).

The noise temperature of the pre-amp has risen. This is common on par-amp systems, and can often be corrected by adjusting pump power using solar testing to verify optimum adjustment.

The gain of the pre-amp has dropped significantly.

When systems fail to pass bit error rate or notch power ratio tests, a straightforward sequence can be followed. Before any automatic test, the validation system performs a self check, and is known to be good. If the output of the receiving system is bad, then the problem is within the receiving system or in the interconnections between the receiving and validation system. Interconnection problems can be quickly checked by observing signal levels in the receiving and validation system receivers. If necessary, the RF level can be increased and decreased manually to verify that all patching is correct. If patching is correct, and the receiving system fails the tests, alternate test points should be input to isolate the problem. For example, if the failed input is the combined signal from the recorder; first patch the combiner pre-d direct; next the receiver RH and LH pre-d; then the P-band input from the multicoupler. The problem can then be isolated to the recorder, combiner, receiver, or front end.

6.2.2 Test Procedures

The descriptions in the following paragraphs refer to the Validations System Block Diagram, Figure 1.

Solar Testing - The antenna to be tested must be designated and patched into the RF Processing Unit (U/C 0020). Also, the frequencies to be tested and current solar flux value at 2.8 GHz must be provided. (Solar flux is given as a number from about 50 to 200. This refers to 50 and 200 x 10^{-26} watts/M^2Hz. For simplicity, the validation system input requires only three digits such as 050, 200, etc. The exponent is accounted for in software. Frequency is entered as a four figure number; i.e., 2250 corresponds to 2250.5 megahertz, with the computer program adding the 0.5 megahertz for the IRIG S-band frequencies.

When a solar test is designated, the validation system performs a SELF check on the pertinent equipment. Initially, the signal generator (U/C 0400) is patch to the self test receiver (U/C 0010) through the RF attenuator (U/C 0050) and downconverter (U/C) 0020). The receiver gain is set, it is tuned to the designated frequency, and the RF attenuator set to a value which provides a power meter reading similar to the reading expected during testing. The

attenuator is then changed 10 dB, and the power meter reading again obtained. The change in readings is used to check the linearity of the receiver and wide dynamic range amplifier. In addition, the power meter is read ten times for each condition, and all corresponding readings must be within 0.1 dB. This ensures that the receiver/amplifier gain is not drifting.

Upon completion of the SELF check the validation system patches the RF input to the self test receiver, and directs the operator to point the antenna to a particular azimuth and elevation which represents cold sky. (This is typically at the current elevations of the sun, and several beamwidths in azimuth behind the sun). Upon acknowledgment, the power meter is read. The operator is then directed to point the antenna to a particular azimuth and elevation which corresponds to the sun, and the power meter is again read. (The sun's position and cold sky position are computed by the validation system). Finally, the operator is directed to again point the antenna at the cold sky. The power meter again read. The first and last cold sky power readings must agree to within .2 dB, otherwise a change in gain has occurred, and the measurement must be repeated.

The validation system computes $M' \doteq 10 \log_{10} G_R/T_S$ from the following inputs and measured data:

Antenna (aperture correction factor is stored)

Solar Flux at 2.8 GHz (3 digits)

Cold sky to sun power change

Frequency (corrects 2.8 GHz flux value to the frequency of interest)

The validation system makes a pass/fail decision based on comparing test results to values which are stored in memory. The following define the parameters which are matched in the comparison:

Antenna, polarization, frequency.

If a test is successful, and a "green" condition for the sun has been entered, the reading obtained is averaged with the current value stored in memory. Up to 5 frequenies for both RH and LH can be run in a continuous automatic sequence. Results and pass/fail decisions for all 10 tests are output for operator review.

Bit Error Rate Testing - In order to conduct a valid bit error rate test, the following parameters must be specified: Code (NRZ-L, BiØL); bit rate; premodulation filter type (30 or 42 dB/octave); premodulation filter setting; peak RF deviation; RF frequency; type of modulations (FM or PM). For SGLS testing, the subcarrier to be modulated must also be specified. With this information, the validation system configures the BER test set transmitter (U/C 0100) to provide the code and bit rate specified; connects the transmitter output to the proper premodulation filter (U/C 0610 or U/C 0620) through the video matrix switch; sets the premodulation filter cutoff frequency; connects the filtered PCM to the deviation attenuator (or SGLS baseband modulator and its output to the attenuator); adjust the deviation attenuator to a specific value for the specified RF deviation, sets the transmitter modulation to FM or PM, and sets the RF to the specified frequency with the programmable frequency synthesizer (U/C 0060). Refer to Figure 1.

Next, the validation system conducts a system SELF test. The RF signal is patched via the U/C 0020 downconverter to the self test receiver. The IF, demodulator, and the video filter are set in accordance with the bit rate, code, and deviation. The receiver video is connected to the U/C 0200 bit synchronizer via the video matrix switch #2 (U/C 0400). The synchronizer's output is connected to the U/C 0100 BER test set receiver. In SGLS testing, the SGLS receiver video can be patched to the U/C 0800 SGLS demodulator unit (U/C 0800) and the appropriate output is connected to the bit synchronizer. The programmable RF attenuator is set to values which produce approximately 10^{-6}, 10^{-5}, 10^{-4}, 10^{-3} and 10^{-2} error rates. Twenty readings are taken, and eighteen averaged. The high and low readings are rejected. The attenuator settings and averages are stored.

The next step is to connect the RF signal into the site receiving system, and the antenna signal to the RF input of the self test receiver. The receiver is placed in the manual gain control mode, the RF attenuator increased to maximum, and the power meter read. The RF attenuation is then decreased until the power meter reading increases 3 dB. The attenuator

setting is referenced as the 0 dB setting, and must agree within $\pm$ 1 dB of the value obtained during solar calibration. Note than the attenuator cannot be set to a value which produces exactly a 3 dB rise, as it can only increment power in 1 dB steps. To maintain accuracy, the power meter reading is used to interpolate to tenths of a dB. For example, if an attenuator setting of 44 dB produces a rise of 3.4 dB on the power meter, then an attenuator setting of 44.8 dB would have produced precisely a 3 dB rise. Thus, 44.8 dB is stored as the 0 dB reference setting.

The answer is obtained as follows:

$P_1 = KT_sBA_1$ - first attenuator setting

$P_2 = KT_sBA_1 = S_1A_1$, where S_1 represents the input signal power from the RF generator.

$$\frac{P_2}{P_1} = 1 = \frac{S_1}{KT_sB}$$

$$\text{Therefore } KT_sB = \frac{S_1}{\left(\frac{P_2}{P_1} - 1\right)}$$

As we wish the input signal to be equal to KT_sB (the noise power) we must increase attenuation by a factor equal to $\left(\frac{P_2}{P_1} - 1\right)$

In our example, $10 \log_{10} \frac{P_2}{P_1}$ is 3.4 dB.

Taking the antilog, gives $\left(\frac{P_2}{P_1}\right) = 2.21$.

and $\left(\frac{P_2}{P_1}\right) - 1 = 1.21$. Finally $10 \log_{10} 1.21$ is 0.8 dB, the amount the attenuator should be increased to provide exactly a 3 dB rise.

The 0 dB setting obtained is referenced to the bandpass filter bandwidth (see U/C 0020, Figure 1) which has a 3 dB bandwidth of 2.1 MHz. The validation system then computes the 0 dB attenuator setting for the bandwidth of the receiving system. For example, if the specified bandwidth for the test is 1 MHz, the attenuator setting which produces 0 dB in 1 MHz is 3.3 dB. Hence, in relationship to the previous example, the attenuator setting which would produce 0 dB in a 1 mHz IF is 44.8 + 3.3 = 48.1 dB.

The designated pre-d input from the receiving system is connected via the test point selector (U/C 0500) and video matrix switch to the translator in the self test receiver. The receiver is placed in the pre-d playback mode. If post-d or SGLS is designated, the video is connected via the video matrix switch to the bit synchronizer. The RF attenuator is then adjusted until approximte data rates of 1×10^{-6}, 1×10^{-5}, 1×10^{-4}, 1×10^{-3} and 10^{-2} are obtained. The equation of the expected setting must be within $\pm$ 1 dB of the setting which produced the measured error rates for the given format. Otherwise, self test fails.

Combiner Testing - Combiner testing can be conveniently conducted while the system is set up for bit error rate testing. The primary change is that the RF signals are connected to the combiner tester (U/C 0020) and then to the site RF Patch Panel. As the combiner tester introduces additional attenuation, the attenuator must be adjusted until an error rate of approximately 1×10^{-4} is obtained from the RH (or LH) only. The combiner output is then tested with no fading, and the error rate must be better than 10^{-4}. This verifies that an improvement in data quality has been provided by the combiner under static conditions. Fading is then begun by connecting a 500 Hz sine wave from the waveform generator (U/C 0030). This causes 500 fades per seconds on each channel but each channel fade is independent of the other, i.e., there is always one "good" channel at any instance of time. The validation system provides a "pass" decision if the error rate of 18 averaged samples (high and low of 20 thrown out) is better than 1×10^{-4}.

Notch Power Ratio Testing - The information required to conduct an NPR test consists of the following:

. Noise bandwidth, i.e., low pass and high pass filter settings of the noise transmitter (U/C 0080).

. Notch filters to be used. Three are usually selected, corresponding to the low, mid, and high frequencies of the noise bandwidth specified.

. RF deviation desired.

. RF Modulation (FM or PM)

. RF frequency

. Pass/fail criteria, notch depth in dB.

From this information, the validation system sets up the noise transmitter and the proper self test receiver, IF bandwidth, demodulator, and video gain.

The validation system connects noise transmitter to the deviation attenuator via the video matrix switch; sets the deviation attenuator to provide the specified deviation, sets the RF frequency and modulation, and sets the RF attenuator to a value which provides a strong signal to the self test receiver via the downconverter. The receiver video is then patched to the noise receiver (U/C 0070) via the video matrix switch (U/C 0400).

Initially, self test checks are made. The noise receiver is switched to the "calibrate" mode and output level checked at each of the specified notches. It must be within +7 to +13 dBm. Next, the output level is read for each designated notch with the noise receiver in the normal mode. The level must be within a range of -10 dBm to +10 dBm. Finally, the designated notches are switched in at the transmitter sequentially, and the output power read for each notch. The ratios must be at least 3 dB larger than the specified pass/fail criteria, otherwise it is not possible to verify whether the actual receiving system meets the criteria.

In the test mode, the RF is connected to the receiving system, and the RF attenuator adjusted to provide a strong signal at the pre-amp input. The pre-d output of the receiving system is connected to the self test receiver up translator via the test point selector and video matrix switch. The self test receiver is switched to the "playback" mode. Notch power ratios are then obtained sequentially, as discussed above. The results must exceed the specified criteria.

The video from the receiving system may be patched to the noise receiver via the video matrix switch. The output level of the noise receiver is checked to ensure that the input level is within a range of -10 dBm to +10 dBm. If not, as in all modes, an error is indicated to the operator. Tests are then repeated at a low RF signal level.

SOLAR CALIBRATION 30 FT. ANTENNA DAY 115,1977 1641 HRS GMT

SOLAR FLUX = 76 SUN CONDITION GRE APERTURE CORRECTION = 0.39

FREQ	POLARITY	COLD	SUN	DIFF	M'	OOB
2221.5	LH	-19.05	-5.69	13.36	18.0	-112.9
	RH	-18.88	-6.30	12.58	17.2	-112.0
2263.5	LH	-20.93	-8.54	12.39	17.1	-112.0
	RH	-19.40	-6.92	12.48	17.2	-112.1
2288.5	LH	-20.50	-8.22	12.28	17.1	-111.9
	RH	-21.06	-8.99	12.07	16.9	-111.7
2221.5	LH	-19.07	-5.65	13.42	18.1	-112.9
	RH	-18.87	-6.27	12.60	17.2	-112.1
2263.5	LH	-20.97	-8.52	12.45	17.2	-112.0
	RH	-19.42	-6.88	12.54	17.3	-112.1
2288.5	LH	-20.50	-8.19	12.31	17.1	-112.0
	RH	-21.03	-8.98	12.05	16.8	-111.7
2275.5	LH	-20.18	-7.72	12.46	17.2	-112.1
	RH	-19.60	-7.32	12.28	17.0	-111.9
2275.5	LH	-20.17	-7.65	12.52	17.3	-112.1
	RH	-19.60	-7.35	12.25	17.0	-111.9

Figure 2 Solar Calibration Results

```
************************** STATION PARAMETERS ******************************
01 OD                        0480    02 LINK                          21
03 MODULATION                  PM    04 CODE                        BIOL
05 BIT SYNC DET               F/S    06 RCVR COUPLING                 DC
07 RF FREQUENCY            2221.5    08 TRANSLATOR FREQ         900000.0
09 IF B/W               1500000.0    10 BIT RATE                345600.0
11 PM DEMOD                1000.0    12 VIDEO B/W               500000.0
13 MAX DEVIATION             90.0    14 PRE-MOD FILTER          500000.0
15 FILTER ROLL OFF            6.0    16 VIDEO AMPLIFIER             30.0
17 DOPPLER FREQ               0.0    18 FADE FREQUENCY             500.0
19 NOISE B/W                  0.0    20 NOTCH FILTER 1               0.0
21 NOTCH FILTER 2             0.0    22 NOTCH FILTER 3               0.0
23 AGC TIME CONST             0.1
**** ANTENNA   STA  RCVR MODE  STA     TAPE   PRE LF RT CO    POST LF RT CO
41     30      109    1    1   109      1         3  2  6          0  0  0
42     30      109    1    1   109      2         3  2  6          0  0  0
43     30      109    1    1   109      3         3  2  6          0  0  0
44     30      109    1    1   109      4         3  2  6          0  0  0
```

Figure 3 Station Parameters – BER

```
01 OD   0480   02 LINK    21          RED FLAG TABLE
** NOISE ** NOTCH         LH         RH          CO
03               0.0      0.0        0.0         0.0
04               0.0      0.0        0.0         0.0
05               0.0      0.0        0.0         0.0
06  POST-D DELTA          0.0
07  TAPE DELTA            0.0
** BER **                10-2       10-3        10-4        10-5        10-6
08  LEFT HAND          -105.0     -103.0      -101.0      -100.0       -99.0
09  RIGHT HAND         -104.2     -102.2      -100.2       -99.2       -98.2
10  COMBINER           -104.2     -102.2      -100.2       -99.2       -98.2
11  POST-D DELTA          0.0
12  TAPE DELTA            0.0
** SOLAR **            30FT LH    30FT RH     35FT LH     35FT RH
13                       15.5       15.5         0.0         0.0
```

Figure 4   BER Red Flag Values

*** BER SYSTEM TEST ***

OD 0480 LINK 21 ANTENNA 30 DAY 115 1726 HRS/GMT

RH ZDB -112.0 LH ZDB -112.9 AT 16417 DAY 115

RF/FREQ 2221.5

BIT RATE 0.3456000E+06 MODULATION PM CODE BIOL

TAPE DECK 109-1 PRE-D

		10-2	10-3	10-4	10-5	10-6
TRACK 3	LH	-109.44	-107.48	-105.28	-103.94	-102.77
TRACK 2	RH	-109.42	-107.28	-105.48	-102.88	-102.40
TRACK 6	CO	-109.60	-107.28	-105.58	-103.57	-103.10

TAPE DECK 109-2 PRE-D

		10-2	10-3	10-4	10-5	10-6
TRACK 3	LH	-109.58	-107.31	-105.38	-104.27	-103.02
TRACK 2	RH	-109.80	-107.16	-105.16	-104.27	-102.77
TRACK 6	CO	-109.76	-106.87	-105.78	-104.32	-102.90

TAPE DECK 109-3 PRE-D

		10-2	10-3	10-4	10-5	10-6
TRACK 3	LH	-109.52	-107.30	-105.49	-104.10	-102.40
TRACK 2	RH	-109.58	-107.08	-105.29	-103.52	-103.30
TRACK 6	CO	-109.48	-107.19	-105.48	-104.32	-102.94

TAPE DECK 109-4 PRE-D

		10-2	10-3	10-4	10-5	10-6
TRACK 3	LH	-109.53	-107.08	-105.55	-103.47	-102.97
TRACK 2	RH	-109.54	-107.06	-105.03	-103.97	-102.60
TRACK 6	CO	-109.46	-107.28	-105.78	-103.85	-103.02

Note:

Tested at 500 hz fade rate

Figure 5 BER Results

STATION PARAMETERS

01 OD	0480	02 LINK	75
03 MODULATION	FM	04 CODE	BIOL
05 BIT SYNC DET	F/S	06 RCVR COUPLING	DC
07 RF FREQUENCY	2275.5	08 TRANSLATOR FREQ	900000.0
09 IF B/W	1500000.0	10 BIT RATE	0.0
11 PM DEMOD	0.0	12 VIDEO B/W	250000.0
13 MAX DEVIATION	300000.0	14 PRE-MOD FILTER	0.0
15 FILTER ROLL OFF	6.0	16 VIDEO AMPLIFIER	12.0
17 DOPPLER FREQ	0.0	18 FADE FREQUENCY	0.0
19 NOISE B/W	204000.0	20 NOTCH FILTER 1	27000.0
21 NOTCH FILTER 2	70000.0	22 NOTCH FILTER 3	105000.0
23 AGC TIME CONST	0.1		

****	ANTENNA	STA	RCVR	MODE	STA	TAPE	PRE LF	RT	CO	POST LF	RT	CO
41	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0
43	30	108	4	1	108	3	12	13	9	0	0	0
44	30	108	4	1	108	4	12	13	9	0	0	0

Figure 6 Station Parameters – NPR

01 OD 0480 02 LINK	75		RED FLAG TABLE			
** NOISE ** NOTCH	LH	RH	CO			
03	27000.0	30.0	30.0	30.0		
04	70000.0	30.0	30.0	30.0		
05	105000.0	30.0	30.0	30.0		
06 POST-D DELTA		0.0				
07 TAPE DELTA		0.0				
** BER **		10-2	10-3	10-4	10-5	10-6
08 LEFT HAND		0.0	0.0	0.0	0.0	0.0
09 RIGHT HAND		0.0	0.0	0.0	0.0	0.0
10 COMBINER		0.0	0.0	0.0	0.0	0.0
11 POST-D DELTA		0.0				
12 TAPE DELTA		0.0				
** SOLAR **		30FT LH	30FT RH	35FT LH	35FT RH	
13		15.5	15.5	0.0	0.0	

Figure 7 NPR Red Flag Values

*** NPR SYSTEM TEST ***

OD 0480 LINK 75 ANTENNA 30 DAY 115 1810 HRS/GMT
RH ZDB -111.8 LH ZDB -112.1 AT 16417 DAY 115
RF/FREQ 2275.5 NOISE B/W 204000.0

		NOTCH 1			NOTCH 2			NOTCH 3		
		27000.0 HZ			70000.0 HZ			105000.0 HZ		
TAPE DECK 108-3 PRE-D										
		NPR	NPRF	NPRI	NPR	NPRF	NPRI	NPR	NPRF	NPRI
TRACK 12	LH	39.0	43.0	41.2	36.0	39.0	39.0	33.0	36.0	36.0
TRACK 13	RH	38.0	43.0	39.7	33.5	38.5	35.2	31.5	36.5	33.2
TRACK 9	CO	39.0	43.5	40.9	36.0	40.0	38.2	33.5	37.5	35.7
TAPE DECK 108-4 PRE-D										
		NPR	NPRF	NPRI	NPR	NPRF	NPRI	NPR	NPRF	NPRI
TRACK 12	LH	39.5	43.0	42.1	35.5	38.0	39.1	35.5	36.0	37.1
TRACK 13	RH	39.0	43.0	41.2	35.0	38.0	38.0	32.5	36.0	35.1
TRACK 9	CO	39.0	43.5	40.9	36.5	39.5	39.5	34.0	36.5	37.6

Note:

Tested at 500 hz fade rate

Figure 8 NPR Results